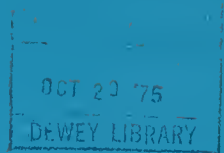


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SIMULTANEOUS ESTIMATION OF THE SUPPLY AND
DEMAND FOR HOUSEHOLD LOCATION IN A
MULTIZONED METROPOLITAN AREA*

Katharine Bradbury, Robert Engle, Owen Irvine and
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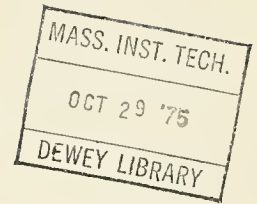
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I. Introduction

This paper reports on work-in-progress of a research project designed to model the growth and internal composition of the Boston metropolitan area, and the location of household and business activities within the area. The overall model is an interlocking system of three submodels: 1) a "macro" model, determining the level and composition of economic activities in the area; 2) a household allocation model, determining the spatial distribution of the household population and housing unit supply over the area; 3) a business allocation model, determining the spatial distribution of the business activity over the area.

The purpose for which this model is designed is policy analysis. Changes in the many policy variables in the model will lead to redistributions of economic activity within the metropolitan area and changes in growth patterns of the region. Comparison of alternative scenarios provides the information upon which policy judgements can be made. In order to

satisfy this objective, it is important to formulate a behavioral model which incorporates a rich choice of meaningful policy alternatives.

Each of the three submodels incorporates its own set of policy issues, which can be examined in isolation. This paper will present preliminary results only for the housing location submodel, but results from other submodels are described in [5], [6], [7], [8]. Because this is only a first stage in our efforts to formulate and estimate the complex relationships determining household location, we will not focus on the policy implications of our estimates. Instead, we report the present findings to give an indication of the promise that our special approach seems to hold and a suggestion as to how policy variables will influence the spatial character of the metropolitan area.

The formulation of our behavioral model is based on three propositions about special characteristics of urban housing markets.

1) Urban housing is an extremely durable good which is spatially fixed. Therefore, the distribution of accommodations at a point in time will extend its influence into a distant future, and public policy can only gradually affect the spatial distribution of the stock of housing. A corollary to this proposition is that supply responses take two distinct forms: a) construction of new units, and b) conversion, retirement and demolition of existing units. Since conversion responses can occur at any time, and since they influence the profitability or desirability of the units, they are likely to be decided upon by owners on a continuing basis. Substantial modifications are therefore possible to the entire housing stock, making this conversion mode of supply response potentially very important in describing neighborhood evolution.

2) Housing is a package of elements, comprising not only structural features, but also land, neighborhood characteristics, local public services, and accessibility to desirable destinations within and outside the urban area. Decisions by economic agents, whether owners, landlords, neighbors, developers or local government, only affect components of the overall housing package.

3) Differences within each of these types of component and across components matter significantly to households, and households differ in their tastes for various configurations of these components. Changes in the attributes of the housing package will therefore have differing impacts on attracting the spectrum of household types.

The overall approach to translating these special features into a model of metropolitan household location will be described in Section II. Section III presents the theoretical concepts and estimates of the demand equations. The theoretical issues and estimates of the supply equations are discussed in Section IV.

II. The Approach

Many approaches have been used to model metropolitan household location. Early models based on gravity concepts of attraction between economic units proved unable to characterize the important behavioral balance between attraction and increasing costs as more agents desire the same location. More recently, large simulation models have been formulated [4], [11], which estimate some parameters of the model econometrically and then impose rather arbitrary market adjustment, supply response or locational choice algorithms to close the system for simulation. Somewhat simpler models based on the equilibrium assumptions underlying the bid rent model [14], [10], estimate closed systems for demand behavior but do not integrate this with supply and have some unattractive features such as no vacancy rates.

Our approach is to formulate a model which can be estimated econometrically from observed aggregate data. The model is based on behavioral assumptions which are appropriate and often testable for economic agents. In order to gain the luxury of estimates of all the parameters of demand functions, supply responses and market adjustment functions, some simplifications must be made. We feel that the simplifications do not impair the validity of the approach, and we present our preliminary estimates as evidence of its promise.

We model a demand for housing accommodation and a supply of such accommodation. Our critical focus is on the spatial distribution of housing, so the chief dimension of both demand and supply is the location of each accommodation. We have divided the Boston metropolitan area into 89

zones: Boston itself divided into 14 Boston Redevelopment Authority districts plus 75 surrounding cities and towns.

The location of any particular accommodation specifies many components of the housing package. For demanders the dimensions of a location which are important include the average types of structural units available, the physical environment of the zone, the demographic character of the neighborhood, the character of local shopping facilities, the variety and quality and cost of public services available (like parks, schools, health and sanitation services, streets, and tax rates), and the accessibility to desirable destinations in the rest of the SMSA. For suppliers the location suggests prospects for revenues from supplying additional units of different types through prices and vacancy rates, and various factors entering into the cost of supplying them, such as vacant land, zoning constraints, sewer systems, and stocks available for conversion.

The selection of political jurisdictions to represent location zones is important. We aggregate to, but not beyond, the political jurisdiction level both because of data availability and because we believe the public service-tax component of the location dimension is especially important to both demand and supply sides. In addition, code and zoning regulations stem from the local governments and exercise significant constraints on housing supply options. The descriptive and theoretical literature suggests that fiscal federalism operates by self-selection of common-minded land-users and their control of governmental instruments to cater to their common interests while excluding disparate groups. This self-selection process should impart a greater degree of homogeneity to land-use patterns within each political jurisdiction than would be expected on the basis of

nonpolitical factors alone. Thus, the jurisdiction may furnish a tolerable degree of situational homogeneity to serve as the observational unit. Clearly, large cities and towns will be less homogeneous; and our segmentation of Boston is a recognition of this.

The demand for housing over these zones is traced in terms of three types of housing occupancy, occupancy by low, middle and high income family households. These categories of demand serve to allocate the urban population over space in a partition of that population which is not only interesting in itself because of its relevance to many socio-economic problems and public policy issues, but is a form that can be determined within our macro submodel. That submodel determines a household income distribution for the metropolitan area as a whole and thus provides a direct input into this household allocation submodel.

These household groups are seen as competitors for the scarce resources of housing accommodations. Presumably all groups would prefer to locate in attractive zones with good public services and high accessibilities. However, because these zones have limited numbers of accommodations heavy competition for these accommodations tend to raise the price of these units high enough to restrict demand to be no greater than the number of units available (while allowing for a vacancy rate that reflects normal turnover of households among units). The aggregate demand curve is the sum of the different household group demand curves.

If the price in a zone rises to ration relatively heavy demand, there will be incentives to suppliers to produce new units there either by new construction or by conversion of old units to new functions. The supply response is articulated both by mode - conversion or new construction -

and by structure type - single family units, units in multiunit structures (2 to 4 units per structure), and units in apartment structures (more than 5 per structure). This breakdown is useful, because new construction technology differs along these lines, and the relative ease or difficulty of structural conversion of existing units is most probably linked to the single-multi-apartment sequence.

The geographic partition of demand and supply in effect treats the market for housing accommodations in each zone as a separate housing sub-market. Various households demand units based in part upon the structural characteristics of the zone's average housing package and in part on a host of other zonal attributes, and the suppliers produce different quantities of units of differing structural type depending on the revenues and costs of supply in that zone both in absolute terms and relative to others. The difference between aggregate demand and aggregate supply for accommodations in a zone is the number of vacant units.

Each zone "clears" its housing market by a combination of price adjustment and quantity adjustment. We employ a vacancy rate to supplement price as a reflection of the market's current state. In a market characterized by durability, moving costs, and lumpy consumption (one unit per household), price does not adjust rapidly or far enough to clear the market in a reasonably short time. The market's immediate and moderate term response to excess demand is registered partly by movements in the vacancy rate. For example, in a tight market, price may not rise far enough to choke off sufficient demand to clear the market (inclusive of a "normal" vacancy rate). Alternatively, in periods of slack demand price may not fall far enough to clear the market; then vacancy rates will rise above normal levels.

Vacancy rates supplement prices in influencing the behavior of demanders and suppliers. The higher the vacancy rate in a zone, the less search is necessary for a demander to find a suitable unit. High search costs discourage demand as do high zonal prices. For suppliers vacancy rates play two roles in defining expected revenues from additional units in different zones: 1) one minus the vacancy rate reflects the probability that an additional unit in the zone will be sold or rented; 2) it points to future adjustments of price within that zonal market.

III. Housing Demand

A. Theoretical Foundations

We perceive the household choice to be the selection of a housing package designated by its zonal location. The package consists of a vector of housing structure and land characteristics, social environmental components, public sector characteristics of the zone, and potential *

* "Potential" rather than "actual" because different households work at different destinations in the SMSA and thus have different actual accessibilities from a common origin.

accessibility from the zone to probable desirable destinations in the SMSA. It is important to note that households do not deal directly in the land market: they demand housing accommodations not land.

The structural and land characteristics of a zone's housing package are described in terms of average or representative units. Variables such as the percentage of the units in a zone which are large, or old, or with luxury plumbing, or in apartment buildings describe the distribution of units. Similarly, the population density suggests the typical amount of land input per unit. These summary measures of course fail to capture the entire distribution of actual occupancies; for example, small houses exist in neighborhoods which have mostly large units, leading to some demand in a zone by household types who prefer small units. Although these observations should average out for large groups of individuals, they may of course be responsible for some noise in the estimates. However, in general, it will

be true, for example, that high income families will demand accommodation in zones which have a relatively high percentage of luxurious units.

A second class of components refers to the social environment of the zone - the nature of the population and the character of their zonal occupancy. We characterize the former by the percent of the zonal population which is nonwhite, and the percentage on welfare; the latter by the residential population density (population per acre). Another variable, the crime rate, refers partly to the social environment and partly to the local public sector's activity.

The third class of components, local public sector activity, is reflected by the pupil-teacher ratio in the school systems and the effective real estate tax rate. It is through these variables that local public policy has its primary effect on the demand for housing.

The fourth class of components of the housing package refers to accessibility. We define the accessibility of a zone to be inversely related to the anticipated real cost devoted to travel by residents of that zone. For each zone the expected real cost to alternative destinations depends upon the location of the destination and the nature of the transportation network. Different household types have different destinations and different modal choices. This is complicated by the facts that the identity of each zone's inhabitants is not determined until after the locational choice has been made, and that some systematic forms of self-selection occur. So the pattern and real cost of trips is a probabilistic matter. In order to capture some sense of this complexity we have, accordingly, constructed a number of accessibility indices: a general job accessibility index by income class in which destinations, their probable importance in relative

frequency of trips, distances, and economic cost per trip, are integrated in weighted form; an index of highway availability; and an index of transit availability (not shown in the present results).

This vector of average structural, social environmental, public sector, and accessibility components constitutes the zonal housing package. Housing choices are influenced by the nature of these packages available in the different zones, but not exclusively. These choices depend as well on the income level of the household which, at one and the same time determines the preferences for different housing package configurations and the desirable tradeoffs between housing and nonhousing commodities. Finally, accommodation choices depend on the prices of the different housing packages available including the cost of finding a suitable unit. Thus in summary, an array of different zonal housing packages is available to any household. The packages differ in their attractiveness, partly depending on the income class of the household. They differ also in prices, the sensitivity to which also depends partly on income class. The household balances off relative attractiveness with relative price, and selects the best compromise.

Income level is handled in our model in a way that illuminates our prime interest in the spatial distribution of the population. Each demand function is formulated as the determination of the share of each SMSA family income class which is located in each zone. Since we partition family households into high, middle and low income classes, we have a separate zonal location demand function for each such class. An observation involves using the set of attributes and price of a given zone (as explanatory variables) to predict the percentage of each SMSA family income class which will reside in that zone.

Price has a special role to play in this formulation. Only because prices differ from one zone to another can we understand the location of the low income families in the most unattractive zones. A simple correlation between the location of low income households and zonal attributes would suggest that low income households love dilapidated housing. This conclusion is however a "reduced form" result which indicates that once the demand and supply equations are solved, which is the real world process of competition for scarce attractive housing packages, low income groups get what is left over, groups with more market power having already had their pick.

In our structural model, the income group which finally locates in a particular zone depends upon the trade-off between price, the zonal search costs, and the attributes of the zonal housing package. Coefficients on zonal attributes for the different household groups reflect relative group preferences for the attribute combined with their relative willingness to exchange money for preferred housing accommodations. It is this differing pattern of coefficients across income classes which leads to that critical characteristic of U.S. metropolitan areas, the sharp socio-economic segmentation of residential neighborhoods and even political jurisdictions.

The specification of the demand for housing determines the number of occupants as a function of market price and vacancy rate, as well as attributes, as in many conventional Walrasian demand functions. The attributes serve essentially to define the commodity and its quality, and the vacancy rate serves as an aspect of the real price of the commodity to the user.

To make clear the connection between our approach and a variety of others, which we shall characterize as perfect market models, let us denote the bid by group i for housing in a particular zone j as P_j^i . This bid may differ from the market price. It will depend on the attributes, X , of the zone through an implicit bid rent function specific to the particular group:

$$P_j^i = g^i(X_j).$$

This formulation makes it possible for different user groups to evaluate the same attributes differently according to their own utility functions and budget constraints.

Since each user will buy one and only one location, unlike the conventional demand theory with multiple commodities, this single locational choice will be based on the competitive bidding of the different users for the finite set of locations - the existing set of accommodations available in the several zones at any time.

In a perfect market the highest bidding group will win the accommodations in each zone, and the winning bid will become the zone's market price. If the actual number of accommodations in the zone exceeds the number wanted by the highest bidding group, the remainder will go to the next highest bidding group, and the market price will be the lower price of the second highest bidding group that actually occupies some of the zone's accommodations. If the actual number of units falls short of the number desired by the highest bidding group, the excess of users will settle in another zone or zones where they are either highest (or second highest in excess accommodation zones). Shortage in the first

zone will force the group to raise their whole set of bid prices in competition to allocate first and second choices among the group. Each set of bid prices implies a different utility level for the group, the higher the bid the lower the utility. All users are allocated to one zone or another in this way. In any zone where they reside the zone's market price will either equal or be less than their bid price.

From the above, the market price in a zone (supposing all accommodations to be homogeneous) depends on the number of accommodations available relative to demands for them. The former depends on past and near-present supply decisions. A zone which would have been first choice for a given group if it had enough units available to keep price down, may drop to second or lower choice with a smaller number of units that would have raised price.

Thus, the demand function for a given group i can be given as a function of both the group's bid and the zone's market price:

$$\text{Number of occupants in zone } j \text{ from group } i = f(P_j, P_j^i).$$

Then $P_j = P_j^i$ for the occupying group in each zone. For that same group $P_k > P_k^i$ in every other zone. Thus a perfect market would imply that function f (in equation (b)) should be a step function: (1) for $P_j = P_j^i$, the whole group locates in j ; (2) for $P_j > P_j^i$, no member of the group locates there. * In a perfect market, the long-run supply response

* There will be a few zones with multiple occupancy. As shown above, in these zones the market price will be below the bid of the highest bidder so f will not strictly be a step function.

to different zones equalizes rates of return to suppliers, setting relative numbers of units that influence household choices. Under certain conditions (as when additional housing packages can be supplied at constant costs *) each zone will be homogeneous with respect to users.

* The package includes density and other nonstructure zonal attributes.

Our treatment diverges somewhat from this treatment. First, in our model supply is taken as jointly determined with prices and demand, but we do not assume that our observations reflect long-run supply equilibrium. Relative numbers of units available in the different zones do not establish perfect user homogeneity. Thus, for any zone competition results in $P_j \leq P_j^i$ for user groups. Second, we do not assume that all users are in their long-run equilibrium. High moving costs prevent users from being in perfect adjustment to relative prices in the different zones at every moment.

Third, we introduce vacancy rates as a market adjustment variable. At any time a market clearing identity is fulfilled:

Number of units available in zone $j = \sum_i$ (number of occupants of group i) + vacant units.

As noted earlier in this paper, we assume that price does not adjust rapidly to market changes, so vacancy rates represent a residual adjustment and act therefore as an additional proxy with price of the current state of the market; in addition they reflect the cost of search for appropriate housing units in a zone and so are a genuine part of the real price of housing in the zone.

Finally, our model deals with accommodations that are not uniform in each zone but are varied. Members of different groups can find different kinds of accommodation in the same zone.

For all these reasons we estimate each group's demand function as a continuous function of market price, vacancy rate and implicit bid price - i.e., the g^i function of zonal attributes:

$$\begin{aligned} \text{Number of occupants in zone } j \text{ from group } i &= f^*(P_j, VR_j, P_j^i) \\ &= f^*(P_j, VR_j, g^i(X_j)). \end{aligned}$$

B. Empirical Results

The demand by a particular household group for housing in a particular zone depends upon the zonal housing package attributes, the cost of the search necessary to find a suitable unit in the zone, and upon the price level prevailing in the zone. It also depends, however, upon the prices, search costs, and attributes of other zones which are close substitutes for the zone. In general, the demand in any zone must depend upon all the prices in all the zones, the costs of search in all the zones, and upon all the housing package attributes available in all other zones. Unfortunately, the strength of the cross-elasticities will vary endogenously. As a simple first solution, the price, search costs, and the attributes of each zone were taken relative to the SMSA average for that variable.

The price variable is designed to be the price per unit of a standard accommodation in a zone. Using actual sales data, price indices for each zone were constructed with a regression method described in Bailey, Muth and Nourse [3] and illustrated with the same data in Engle [9]. This method eliminates the need to identify the standard unit, but hinges on the assumption that different types of units in a zone experience similar rates of price change. Tests of this hypothesis were generally accepted. Because this price series is an index, it is only possible to determine the

rates of change of prices in different zones. The model is therefore estimated in rate of change form. *

* There were some zones for which these indices could not be constructed. Therefore the rates of change over the 60-70 decade were projected upon the census rates of change of value and composition to obtain an approximation for the other zones.

The model as described above can be formalized by a series of demand functions for each family income group:

$$(1) \quad D_z^y / \bar{D}^y = D^y (A_z^1 / \bar{A}^1, A_z^2 / \bar{A}^2, A_z^3 / \bar{A}^3, A_z^4 / \bar{A}^4, P_z / \bar{P}, V_z / \bar{V})$$

where D_z^y is the number of households of income y who demand location in zone z , and a bar represents the SMSA average of this variable. A^1, A^2, A^3, A^4 are the vectors of attributes corresponding to structural and land attributes, social environmental attributes, public service attributes and accessibility attributes respectively, P_z is the zonal price, and V_z the initial zonal housing unit vacancy rate which is a measure of search costs. Because the available price variable is an index of price changes, the model was estimated in terms of decadal differences. A linear form was chosen as a trial specification. Two stage least squares was used to estimate the coefficients of these equations because of the simultaneous nature of a number of the right hand variables. The change in price, the change in all the structural attributes, the change in population density, Δ POPDEN, the change in the percent nonwhite, Δ BLACK, and the change in the percent of households on welfare, Δ WELFARE, were all treated as endogenous variables.

The estimated coefficients for the LOW, MIDDLE, and HIGH income family household groups are shown in Table 1, with variable definitions in the appendix.

All equations are estimated with 2SLS with indicated variables treated as endogenous. The sample is the 89 zones of the Boston SMSA. Asymptotic standard errors and other diagnostic information are presented for each equation.

These preliminary results display encouraging consistency with theoretical expectation. The a priori expectations for signs of the coefficients are displayed in Table 1. In 80% of the cases, these are satisfied and in only two cases are the a priori expectations rejected at the 95% level for a one tailed asymptotic test. The coefficients themselves are elasticities: A coefficient value of .5 in Table 1 means that if the zone were to increase its relative supply of the attribute by 1.0%, the zone's share of that income group would increase by .5%.

All three estimated coefficients in the change in price variable, Δ PRICE, were negative as economic theory would lead us to believe a priori. The standard errors of this variable, however, were large, making the confidence intervals wide. It is interesting to note that low income families are much more sensitive to the price of the housing package than either of the two higher income groups. This is reasonable, considering that many households in this group are living in poverty. Another complicating factor contributing to these results is that many of the two upper income groups are homeowners rather than renters. A homeowner, viewing his house as an investment as well as a consumption good, may desire to purchase a unit in a zone where prices are rising rapidly, with

Table 1

ESTIMATES OF HOUSEHOLD DEMAND EQUATIONS BY TWO STAGE LEAST SQUARES †

AND ASYMPTOTIC STANDARD ERRORS

(All variables are 1960 to 1970 changes in ratios to the SMSA mean except where noted)

	A PRIORI EXPECTED SIGN			ESTIMATED COEFFICIENTS (STANDARD ERRORS)			Type
	Low	Middle	High	Low	Middle	High	
Δ PRICE	-	-	-	-.49 (.35)	-.20 (.26)	-.19 (.58)	endogenous
VAC RATE ₆₀	+	+	+	-.06 (.06)	.11* (.04)	.24* (.09)	exogenous
Δ BATHROOMS	+	+	+	-.01 (.10)	.26* (.08)	.74* (.17)	endogenous
Δ LARGE	+	+	+	.02 (.19)	-.30* (.15)	-.41 (.32)	endogenous
OLD ₆₀	-	-	-	-.09 (.14)	-.20* (.11)	-.62* (.23)	exogenous
Δ POPDEN	-	-	-	-.02 (.03)	-.02 (.03)	-.08 (.06)	endogenous
BLACK ₆₀	?	-	-	.05* (.03)	-.05* (.02)	-.09* (.04)	exogenous
Δ BLACK	?	-	-	.08* (.03)	-.06* (.03)	-.14* (.06)	endogenous
Δ WELFARE	+	-	-	.05 (.06)	-.07* (.04)	.04 (.09)	endogenous
CRIME ₇₀ ††	-	-	-	-.04 (.04)	-.03 (.03)	-.17* (.07)	exogenous
Δ EFFTAX	-	-	-	-.08 (.12)	-.02 (.09)	-.21 (.20)	exogenous
Δ PTRATIO	-	-	-	-.31* (.12)	-.01 (.09)	-.07 (.20)	exogenous
Δ JOBACC_	-	-	-	-.47* (.22)	.37* (.16)	.27 (.38)	exogenous
Δ HIGHWAY	-	-	-	-.002 (.07)	-.05 (.05)	-.23* (.12)	exogenous
CONSTANT				.63 (.33)	.37 (.25)	.83 (.55)	
R ²				.39	.50	.52	
SSR				2.13	1.24	5.87	
STD ERROR				.17	.13	.28	

† The instruments used with the endogenous variables were the exogenous variables of the supply equations and the 1960 predetermined values of the endogenous variables.

†† The 1970 level relative to the SMSA mean used because lacked 1960 data.

a view to capturing future capital gains, rather than being deterred by rapidly rising prices.

As discussed in Section II, each zonal housing market is viewed as adjusting through both price and quantity variations in all but the very long run. Excess zonal demands or supplies are registered by both zonal price movements and by movements in the zonal vacancy rate. The beginning of the decade zonal vacancy rate, $VAC\ RATE_{60}$, was included in the demand equations. In the equations for HIGH and MIDDLE income families, the estimated coefficients on $VAC\ RATE_{60}$ are positive as a priori economic theory concerning the costs of search would lead us to expect. These coefficients are also statistically quite significant. Also they increase in size from the LOW equation, which exhibits an insignificant negative coefficient, through the HIGH equation's coefficient. This is consistent with the higher opportunity costs of search for high income households.

Four structural attributes were utilized in these preliminary regressions: the percent of a zone's units that are large units (≥ 7 rooms), $\Delta LARGE$, the percent of a zone's units that are over thirty years old, OLD_{60} , the percent of a zone's units that have greater than one bathroom, $\Delta BATHROOMS$, and the population density, $\Delta POPDEN$. The signs of the coefficients on $\Delta BATHROOMS$ increase in size from the LOW to the HIGH income group equation supporting the a priori expectation of a much stronger preference for more luxurious larger units by higher income families. The elasticity coefficients on this variable, in addition to being large in absolute size, are also statistically very significant, the elasticity coefficient of .74 being the most economically and statistically significant coefficient in the HIGH income equation. The coefficients on OLD_{60} all are negative, as the assumption that households prefer newer units, *ceteris paribus*, would

lead us to expect a priori. These coefficients increase in absolute size from the LOW income to the HIGH income equation, confirming the a priori expectation that higher income households have a much stronger preference for newer, more luxurious units. The elasticity coefficient estimates on OLD_{60} in the equations for MIDDLE and HIGH are statistically quite significant in addition to being among the largest in absolute size. Indeed, these variables characterizing the structural characteristics of a zone's typical housing package play a very important role in these estimated demand equations.

Population density also proved to be an important variable: all the signs are negative as expected. The hypothesis that the higher the family's income, the stronger its preference for low density also was supported by the estimated coefficients which increase in absolute size from the LOW to HIGH equation. This result reflects the preference of high income families for space, a preference which partially explains the high income suburban ring so common in U.S. metropolitan areas.

All four of the social environmental attributes were found to enter one or more of the equations in a significant manner. The percent of the households in a zone which were nonwhite was included to capture the preferences of whites to live segregated from nonwhites. Both the beginning of the decade zonal percent nonwhite, $BLACK_{60}$, and the change in the percent nonwhite, $\Delta BLACK$ (treated as endogenous), were included in these demand equations. The estimated coefficients on both these variables turned out to be statistically significant in all three equations. The signs on both these variables were positive for LOW income families, partly reflecting the fact that a nontrivial portion of this group was

itself nonwhite, the majority of the nonwhite households in the Boston S.M.S.A. being low-income households. * The signs of the estimated coefficients

* The dependent variables of these estimated equations contain households of all races. Currently we are separating out the nonwhite households in hopes of estimating separate income class demand equations for them, and examining whether LOW income whites have similar preferences to the HIGH and MIDDLE income groups in this regard, or are closer to the present mixed LOW group.

of both of these variables are negative in both the MIDDLE and HIGH income group equations, strongly confirming the preference for segregation by Boston S.M.S.A. whites. Also the larger negative coefficients on both the variables in the HIGH income equation implies that this segregation preference is more intense among the higher income whites. It is noteworthy that this segregation preference appears quite strongly even controlling for the higher welfare population, the higher tax rates, the poorer schools, and the higher crime rates often cited as reasons for the flight by whites from integrated central city zones to the segregated suburban communities.

Approximately 65.6% of the LOW income households were on welfare in 1970. Therefore it was expected that the coefficient on the percent of a zone's households on welfare, Δ WELFARE, would be positive in the LOW equation. The estimated coefficients on welfare partially support the hypothesis that the existence of a large welfare population in a zone constitutes a "negative externality" to middle and high income families independent of

the fiscal burden caused by their presence and independent of the crime rate to which a large welfare population may contribute disproportionately. A priori, all family households were expected to prefer low relative crime rates. This was supported by the negatively signed coefficients on CRIME₇₀ obtained in all the estimated equations.

The local public service variables also proved significant. The importance of the quality of the local public schools as part of the housing package offered in a zone is supported by our results. All three estimated coefficients on the PTRATIO were negative as expected. In addition, all three family groups also appear to be sensitive to the local effective tax rates in the a priori expected manner. High-income families seem to be the most sensitive to (or adept at avoiding) high relative tax rates.

A priori, it was felt that all income level households would prefer more accessibility to less. The larger the relative value of the general job, accessibility index, Δ JOBACC_, the less is the zone's accessibility. Therefore a negatively signed coefficient was expected. Some urban economists have argued that the poor have the strongest preferences for accessibility. However, the rich would seem to have the highest opportunity cost to their time spent in commuting. Therefore the expected pattern of the size of the coefficients on Δ JOBACC_ was uncertain. As can be seen from Table 1, the large sized, statistically significant, negatively signed estimated coefficient on Δ JOBACCL in the LOW equation indicates that low income families do prefer locations that are highly accessible to their jobs. The positive coefficients on Δ JOBACC_ in the MIDDLE and HIGH equations suggest that these households are less averse to job travel than we expected. We are investigating this further with improved accessibility measures.

The negatively signed estimated coefficients on the highway index in all three equations indicate that the negative externalities generated by highways crossing a zone are significant. These elasticities increase monotonically in absolute size with the income level of the household as would be expected a priori; i.e., high-income families are the most sensitive to the negative externalities generated by highways. The automobile is the major source of pollution and congestion in the Boston SMSA; these results suggest that all households are sensitive to the externalities it generates.

IV. The Supply of Housing

Our model of housing supply focuses on the number of housing units made available to households in a zone and their structure type (in terms of units per structure). The actors whose behavior is being modelled are housing suppliers of two basic types: builders of new units and owners of existing units. Conversion supply is treated on parity with new construction, but with expectations that the determinants of the two will differ to some extent.

Suppliers of housing presumably compare the present values of revenues and costs when deciding upon a housing investment just as would an investor in any enterprise. The quantity and type of housing forthcoming in any zone in a particular period will be related to the costs and revenues of producing these units at the particular location. A careful analysis of these costs and revenues for different structure types and modes of supply provides the structural model behind the supply equations.

The decision to supply a unit of housing is a decision to combine factors of production, such as capital, labor, land, and possibly an existing structure which can be converted, to produce a new unit. The amount of housing which is produced in a zone will therefore depend upon the price and possibly the quantity of the factors which are available in the zone, and the final selling price of housing. Because capital and labor are equally available at all zones in an SMSA and approximately at the same price (except perhaps for the availability of credit to the ghetto), the major differences across zones will be in the land and convertible structure factors, and in output prices.

We begin our exposition of the housing supply model with a discussion of new construction and how the land market interacts with new supply decisions. Then the determination of structure type of new units is analyzed. Finally, a model of conversion supply is proposed and estimated. This separate treatment should not obliterate the fact that these sources and types of housing supply interact and compete in and across all zones, both in the input markets and in the housing market as a whole, where consumers are faced with the full array of sources and types of units.

A. New Construction

The most important input price variation for producers of new housing units in a metropolitan area is the price of land. The locational variation in the price of land is the central focus of much urban land use literature and is important in this housing supply model as well. William Alonso [1], [2] and others (Richard Muth, Edwin Mills, Lowdon Wingo) have developed models in which competition among different kinds of users for scarce urban land determines the price of land in each location and allocation of land among user types. Starting from the assumption that the only differences in the marginal revenue productivity of different locations in an urban area are due to distance to a central market, whose proximity is valued differently by different users, the models predict concentric rings of land devoted to different urban uses, and declining densities of any use as distance from the center increases.

But metropolitan development does not take place literally as these land use models depict, with all land in a given annulus used up (at varying densities) before the next annulus is bid away from the (given base price) agricultural use. In fact, we observe parcels of undeveloped

vacant land at all distances from the "center", and the percent vacant varies in a systematic way, increasing with distance from the center. The price of this vacant land, other than at the very edge of the urban area is certainly not zero (or some constant agricultural price). The price reflects the price of comparable (in a location sense) developed land, and hence relates to alternative uses to which a lot could be put.

To understand the existence of vacant parcels in any annulus within the urban area, we must assume that some of the demand (for the fixed amount of land in the annulus) is by demanders who choose not to develop the land to whatever its most profitable current use is. Vacant land yields no revenue in the present, and in fact is liable to taxes, yet buyers hold it vacant. These buyers are willing to pay as much as producers who turn it to revenue-yielding purposes (or if they already hold it vacant, they are willing to resist such bids by producers). It must be that they expect other returns. Specifically, holders of vacant land speculate on rising land values. When these speculators choose to "cash in" their capital gains, they can be seen as suppliers of vacant land to producers of housing or nonresidential services. If speculators' reservation prices (below which they wish to hold land vacant) are distributed randomly (perhaps because of risk preferences and expectations), then the land supply curve has its usual upward slope: the lower the market price, the larger the number of speculators whose reservation price is not exceeded, hence who hold land. Taxes on land value will reinforce this slope, since they increase carrying costs of holding land vacant as its price rises.

As demand by other land users in the annulus grows, the opportunity cost of holding land vacant is higher, and hence less of it is held.

"Other" demand for land is derived from business use, use by the public sector and other institutions, and residential land use. We expect this derived demand for land in any one location (or annulus) to be quite price-elastic, since close substitutes (nearby parcels) exist. Thus demanders arbitrage across land markets to keep prices in line with marginal revenue productivity (which depends on "accessibility" in the eyes of the highest bidder). One thus observes the pattern of land prices and land use densities predicted by land use models - declining from the center - and in addition observes increasing shares of vacant land as one moves from the center. As population and/or income in an urban area grow over time, the derived demand for land in all uses increases, and vacant land at each location within the urban area declines at the same time as more land is absorbed into the urban fringes; the metropolitan area develops up and out, intensively and extensively, simultaneously.

In the context of this housing supply model, each "location" to which the analysis is applied is a city or town or district with fixed total land area. In each zone, speculators are assumed to behave in the same way, "supplying" increasing fractions of the total land to other uses as demand (hence price) increases. Thus a relation making the price of land a decreasing function of share of land vacant is assumed to hold across towns. This assumption does not imply that holders of vacant land control the price of land, for in fact the price is the outcome of interaction among all land users in the market for land. Rather, this speculative model is chosen as a useful way to look at "land supply" to housing producers and others. Similar stories can be told for subdivision of occupied lots, reclamation of marginal acreage and many other forms of land

supply. The outcome of this approach is that the percent of vacant land is a good indicator of the price of land.

Other inputs into new housing production may be limited for the whole urban area, but each zone is a small part of that area and hence suppliers can be considered to perceive these inputs as perfectly elastically supplied.

We model new housing as produced by a competitive industry with a constant returns to scale production function, (1) $Q = Q(L,N)$; where Q is total housing units produced and L and N the amount of land and nonland inputs, respectively. This production function implies a relationship between output price and factor prices, (2) $p = p(r,n)$; where r and n are the price of land and nonland inputs, respectively, and p is the price of a unit of housing.

If the elasticity of substitution between land and nonland inputs in the production of housing is not zero, producers will use less land and more nonland inputs to produce a unit of housing where land price is higher. Thus the land input per housing unit is a function of the price of land (or really the factor price ratio):

$$(3) \quad L/Q = m = m(r/n) \quad \text{or} \quad L = m(r/n)*Q$$

where L is total land used by housing suppliers, hence m is the land per unit, or lot size.

The previous section developed the proposition that the price of land can be expressed as a function of the fraction "developed", i.e.,

$$(4) \quad r = r(V/T) = r(v) = r((T-L-J)/T)$$

where T is total land area in a town; L, as above, the land used in new housing production, J the other "already-developed" land area, and V the amount vacant, and $v = V/T$. For simplicity this function is often assumed to have a constant elasticity.

If all these functions are well-behaved, then we can derive from (2), (3) and (4) a "supply function" for housing in each town which relates quantity produced to output price, incorporating the effect of land development on the factor input price:

$$(5) \quad p = f(Q/T) \quad \text{or} \quad Q/T = s(p) = f^{-1}(p)$$

The Q/T can be thought of as gross residential density, or more simply as a quantity of output along a supply curve which has been standardized for the size of city or town. The price of land rises as more land in a town is developed. For the housing new construction industry, this rising factor supply schedule causes supply to be an increasing function of price, in spite of constant returns to scale in production.

The shape of this supply curve depends crucially upon two of the underlying relationships - how responsive lot size (and hence total derived demand for land at any output level) is to changes in the price of land, and how responsive the price of land is to changes in the quantity developed (or demanded by housing producers).

Taking percentage derivatives of supply equation (5) at a point, we derive a relation between output prices and quantities given by Muth [13, p. 228]:

$$(6) \quad \frac{dQ}{Q} = \left(\frac{k_N^{\sigma+e_L}}{k_L} \right) \frac{dp}{p}$$

where k_N and k_L are the factor shares, e_L is the price elasticity of land supply, σ is the elasticity of substitution between the factors of production, and the prices of nonland inputs are held constant. If $\sigma = 1$, the factor shares are constant, and the price elasticity of housing supply varies with the price elasticity of the supply of land to new construction. The speculative model of vacant land release suggests that the price elasticity of residential land supply is greater where there is more vacant land. Thus we would expect housing to be more elastically supplied in the suburbs than in dense central city areas. Our econometric specification must recognize this variation in elasticity across the metropolitan area.

If σ is less than unity, * the factor shares are a function of

* Muth offers support for this hypothesis in [12], pp. 82-83 and p. 315.

factor prices, and land's share in housing will be greater in the city center than in the suburban fringe of a metropolitan area where land is less expensive. Thus in the non-Cobb-Douglas case, equation (6) implies a second factor contributing to the higher price elasticity of housing supply in the less-developed areas of the metropolitan region. The effect of the smaller price elasticity of land supply is augmented by the greater sensitivity of output price to land price (higher land share) in producing a lower price elasticity of housing supply in more central parts of the urban area.

There is an additional element varying across zones which directly affects the new housing production function. The amount of land in other

uses, just like the amount of land consumed by housing producers, affects the price and elasticity of supply of land. Housing producers in a town with increasing "other land use" face higher land prices, *ceteris paribus*, according to (4). Thus we need to include in (6) a term reflecting any shifts in the supply of land curve during the decade. (Differing initial conditions are captured by the initial supply elasticity of land.) The appropriate form for this equation is also derived by Muth [13] and is

$$(7) \quad \frac{dQ}{Q} = \frac{k_N^{\sigma+e_L}}{k_L} \frac{dp}{p} + e_{L,J} \frac{dJ}{J}$$

where $e_{L,J}$ is the elasticity of supply of L with respect to J (other land use), and dJ/J the percent change in J. The greater the increase in other land use, the less land there is available to housing producers, hence the less housing production, *ceteris paribus*. When we assume a constant elasticity in (4) the second term in (7) simplifies to dJ/L .

In addition to these production function and input market influences, there are other factors impinging on new construction housing supply in a metropolitan area. Because of the lags which characterize housing market price and quantity adjustments and the integer character of purchases or leases (one household to one housing unit), vacancy rates are an important adjustment mechanism in equating supply and demand for housing. Thus builders of new units can be expected to use vacancy rate changes as indicators of the direction of future price movements. Since occupancy rates are almost never one hundred percent, they also indicate the probability of actually selling or leasing a unit when it is made available on the

market. Both of these points suggest that when vacancy rates are high or rising, producers will be discouraged from adding to the housing stock.

Within the separate jurisdictions of a metropolitan area, there are also important government interventions into the operations of the housing "market". Cities and towns in a metropolitan area have various zoning policy tools at their disposal to try to control or direct the residential and nonresidential development of the jurisdiction. Municipalities can zone limited areas for business and commercial use, set up residential sub-areas with differing maximum density limits (height, frontage, lot size), and grant or withhold variances to the rules they establish. Such regulations may simply cause producers to put units they would have built anyway into spatially contiguous homogeneous sub-areas, or they may actually restrict the kind of housing production which occurs in the zone. If producers are restricted from using the land per unit ratio they would otherwise choose, their profits are reduced, and one would expect less housing production. Minimum lot size zoning regulations, for example, when binding, reduce the effective land available to producers.

We derive from (6) and the additional factors discussed above, a supply equation for new construction to be estimated econometrically.

It takes the form

$$(8) \quad \frac{dQ}{Q} = a_0 + a_1(f(v) \frac{dp}{p}) + a_2\left(\frac{dJ}{L}\right) + a_3\left(\frac{d \text{ VAC RATE}}{\text{VAC RATE}}\right) + a_4(\text{OPEN}) + \epsilon$$

where Q , v , p , J , and L are defined above, $\frac{d \text{ VAC RATE}}{\text{VAC RATE}}$ is the percentage change in the housing unit vacancy rate, and OPEN is the fraction of land in the town which is both vacant and not restricted to minimum lot sizes

greater than 25,000 square feet. The function f represents the relationship between percent land vacant and the parameters discussed earlier which enter the price elasticity term: the elasticity of substitution, the factor shares, and the elasticity of land supply. Although we know that $f(v)$ is an increasing function we do not know its exact functional form. For simplicity we assume that f depends on the ratio of vacant land to residential land at the beginning of the period. Therefore we expect a_1 to be positive, a_2 and a_3 to be negative, and a_4 positive.

The supply relation was estimated using decadal percentage changes in the number of housing units in a cross-section of 89 Boston metropolitan area sub-regions. The equation is estimated with 2SLS treating prices and vacancy rates as endogenous. The instruments are taken from the demand equation. Because the equation is nonlinear in the variables, nonlinear functions of the exogenous variables are also valid instruments and several of these are used.

The estimated equation with asymptotic standard errors is given below. The exact definitions of the variables are given in the appendix.

$$\frac{\text{NEW TOTAL}}{\text{TOTAL}_{60}} = .104 + .0651 \left(\frac{\text{VACANT ACRES}_{60}}{\text{RESIDENTIAL ACRES}_{60}} \right) * \Delta \text{PRICE} \\ - (.121) * \left(\frac{\Delta \text{OTHER ACRES}}{\text{RESIDENTIAL ACRES}_{60}} \right) - (.0377) * \frac{\Delta (\text{VAC RATE})}{\text{VAC RATE}_{60}} + (.271) \text{ OPEN} + e$$

Standard error of the regression = .135

F-statistic (4.84) = 14.3

The overall fit of the equation is reasonable and the individual coefficients have small standard errors and a priori sign expectations. In particular, the t-ratios on the price elasticity and the vacancy rate are quite large.

These estimates imply price elasticities of new housing supply from .55 in the open suburbs to almost zero (.0006) in the dense center city. In addition, new housing will be forthcoming as vacancy rates are decreased so the net response due to changing demand conditions will be felt through both price and quantity measures. Alternative land uses do appear to compete strongly for land and will act to discourage new supply. The availability of vacant land which does not face zoning restrictions will lead to new construction.

B. New Construction Structure Types

Having proposed and estimated a model of new construction supply of housing units for geographic zones in a metropolitan area, we turn now to a careful examination of one characteristic of new housing units so produced, their structure type. When the price of land is higher (across zones or over time within a zone), a housing unit is produced with less land relative to other inputs to economize on the more expensive factor. This factor substitution is expected whether we think there are different technologies for different structure types (and each structure type is built where its technology is most profitable), or one technology for different structure types, as long as the one technology has a nonzero elasticity of substitution. If there are different technologies, but one output in the eyes of the consumers, then one technology will be most profitable with given input prices, and the situation is much the same as under the assumption of one technology, except that there may be kinks or discontinuities in the supply function. Equation (3) of the last section implies that for any given land price, the land per unit (lot size)

of new construction is uniquely determined, decreasing as land price increases. If we could define structure types in terms of a range of land/nonland input ratios, given any input price ratio, we would know the structure type of all new construction. This is illustrated in Figure 1.

However, when we actually observe the structure types of new construction in different zones in the metropolitan area, we do not see such unanimity as to the appropriate structure type within each zone. Within the theoretical context of this model, there are several reasons for this lack of uniformity.

First of all, our "observations" are for an entire decade of new construction responses. The model suggests that over that time span, it might well be that residential and other development could cause the price of land to cross a threshold between types, thus making appropriate at least two structure type responses within a town when the decade is taken as a whole.

Second, cities, towns and districts are not entirely internally homogeneous areas, although we treat them as such in the model. We argue that there is more internal homogeneity than similarities across towns. However, neighborhood attributes affect land prices within towns as well, but with a lesser degree of variation. In using these zones as our unit of observation, we have abstracted from this internal heterogeneity. lines between jurisdictions, we may expect some "smearing" near the edges of jurisdictions. If one town's "appropriate" type is singles, and its neighbor's is multi-family units, we may see some overlap at the border.

Third, historical and institutional restrictions interfere with the price of land's deterministic effect on structure type. Zoning, neighbor-

hood effects, and the timing of release of land parcels and their size (whether through demolition, lot splitting, or vacant land sales) may make only one structure type possible on a given lot, even though, given full flexibility, a producer would combine land and other inputs in different proportions.

Finally, there is a measurement or definition problem. The production function implies that the land-nonland ratio responds as a continuous function of the price of land (as depicted in Figure 1); that is, lot size decreases as the price of land increases. What we measure with our census data on structure types (single, multi-family defined as two-to-four units in the structure, and apartments with five or more units per structure) only corresponds very crudely to a measure of land per unit or land to nonland input ratio. A single family unit on a small lot might have less land per unit than a large lot duplex or even a low-rise "garden apartment" complex. Thus we may classify units in the wrong segment of the continuum.

Taking all these effects into account, we still expect the price of land to be a good predictor of structure type. However, rather than an on-off switch between structure types, the relationship between structure type shares of new construction and land price is expected to be smoother, since all the factors discussed above contribute to heterogeneity of types, given land price.

Local government actions such as zoning and provision of sewers can also affect the structure type built by the producer. The availability of sewer lines has been used explicitly by local governments to control development in some areas around Washington, D.C.. It may or may not be cheaper to build any housing unit where sewers are available, because the cost of

internal sewage treatment systems (septic tank) need not be included by the builder, but connections to the sewer system must be built. However, high-rise structures cannot be serviced by septic tanks. Thus sewer availability has a role to play in determining the technological feasibility of different structure types.

Zoning, cited above as one of the interferences between land price and structure type, is a local government policy tool the impact of which can be modelled more explicitly. Zoning regulations generally restrict housing producers' choices in an asymmetric fashion; that is, they set a maximum (e.g., unit per land area density or height) and allow any uses which do not exceed the maximum. We want to model two such types of zoning regulations. One variable is a zero-one dummy for whether the town zoning code allows apartment structures at all. If apartments are not allowed, the apartment share of new construction is expected to be zero. Thus this variable is included by multiplying it ($A = 0$ when apartments are banned) by all the right-hand variables in the apartment share equation. The second type of zoning is the establishment of lot size minimums for part or all of the residential (and vacant) area of a town. The minimum lot size zoning variable measures the percent of the town which is restricted to lot sizes greater than 25,000 square feet. Where this minimum lot size applies, any units built must be single unit structures (surrounded by over half an acre of land). Thus if a town's residential and vacant land is all so zoned, all units built will be singles. If a town has no zoning, the price of land and sewer availability will determine the shares of total new construction which are of each structure type. If minimums apply in part

of a town, singles will be built in that part and land price and sewers will determine what is built in the unzoned areas.

Thus, if in the absence of zoning the model were:

$$\frac{\text{NEW SINGLE}}{\text{NEW TOTAL}} = f(r) + h(\text{SEWER}) + \epsilon$$

$$\frac{\text{NEW APART}}{\text{NEW TOTAL}} = A*g(r) + A*k(\text{SEWER}) + \epsilon$$

(where r is the price of land, A is the apartment banned dummy variable, and f , g , h , and k are functions), then the model including zoning should be

$$\frac{\text{NEW SINGLE}}{\text{NEW TOTAL}} = PZ + UZ*f(r) + UZ*h(\text{SEWER}) + \epsilon$$

$$\frac{\text{NEW APART}}{\text{NEW TOTAL}} = UZ*A*g(r) + UZ*A*k(\text{SEWER}) + \epsilon$$

where PZ is the fraction of land zoned for lot sizes greater than 25,000 square feet, and UZ is one minus PZ , the share unzoned.

The fraction of decade new construction which is single family units and the fraction which is apartment units (five or more units in structure) are therefore modelled as a function of the price of land, zoning, and sewer availability. The share of the new construction which is multi-family units (two to four units in structure) is the residual; that is, total new construction less singles and apartment units.

Land price is proxied, as before, by percent of land vacant at the beginning of the period. The 1960 percent vacant land is entered into the equations as a set of seven dummy variables ($V1-V7$), each for a range of values of the variable. It is entered in this fashion rather than

continuously because, as postulated earlier, land price is not a linear function of percent vacant, and even if it were, we don't expect the shares of new construction single or apartment to be linear functions of land price.

These regressions were run using ordinary least squares. The results were as follows (standard errors in parentheses below coefficients):

$$\frac{\text{NEW SINGLE}}{\text{NEW TOTAL}} = .958 \text{ PZ} - .00278 \text{ UZ*SEWER} + .392 \text{ UZ*V1} + .618 \text{ UZ*V2} + .700 \text{ UZ*V3} \\ (.0425) \quad (.00111) \quad (.119) \quad (.123) \quad (.109) \\ + .799 \text{ UZ*V4} + .828 \text{ UZ*V5} + .970 \text{ UZ*V6} + .768 \text{ UZ*V7} + e \\ (.110) \quad (.0854) \quad (.0881) \quad (.0878) \\ R^2 = .7921$$

Standard Error of the Regression = .157

$$\frac{\text{NEW APART}}{\text{NEW TOTAL}} = .00276 \text{ A*UZ*SEWER} + .518 \text{ A*UZ*V1} + .298 \text{ A*UZ*V2} + .145 \text{ A*UZ*V3} \\ (.00105) \quad (.112) \quad (.117) \quad (.103) \\ + .130 \text{ A*UZ*V4} + .0936 \text{ A*UZ*V5} + .0644 \text{ A*UZ*V6} + .192 \text{ A*UZ*V7} + e \\ (.104) \quad (.0803) \quad (.0815) \quad (.0779) \\ R^2 = .7770$$

Standard Error of the Regression = .149

The progression of coefficients across the categories is what we expect (increasing for singles, decreasing for apartments) except for the last category. In each case, the coefficient on V7 (= 1 if fraction vacant \geq .5) is not significantly different in a statistical sense from that on V6. These coefficients are displayed graphically in Figure 2.

SEWER enters both equations as expected, implying that for each ten percentage points of sewer availability in a zone, an additional three percent of new construction is apartments, not singles, ceteris paribus.

A t-test shows that the coefficient on PZ in the SINGLE equation is not statistically significantly different from unity, which is what the model predicted. The use of the zoning variables multiplicatively (both UZ and A) improves the overall fit (higher R^2 , lower sum of squared residuals) and the individual coefficients in comparison with exclusion of the zoning variables or inclusion as a separate linear continuous variable.

C. Conversion Supply

The second major means of housing stock adjustment is the process of changing existing housing units to provide a different quality or quantity of services. Over ten percent of the 1960 Boston S.M.S.A. housing stock (and almost 20 percent of the 1960 City of Boston stock) had been demolished, lost through other means, or changed by conversion or merger by 1970. Considering the size of the housing stock in comparison with new construction, these data indicate that such processes have an important impact on aggregate housing supply. Our focus in this model for both new construction and conversion-demolition is on changes in the number of housing units and their structure type (units in structure). What we call the "conversion-demolition process" includes a number of distinct activities by property-owners: "converting" a structure by increasing or decreasing the number of housing units it encloses; and withdrawing the units in a structure from the housing stock, through conversion to nonresidential use, or through demolition. Demolition may take place because a structure is worn out or because other uses for the site are more profitable; thus it may be done in order to create open area or to make possible the construction of a new (residential or nonresidential) structure on the site. In the

latter case, only half the process (the demolition) is considered "conversion-demolition"; the replacement structure (if residential) is a part of new construction.

In the discussion of residential new construction, the point was emphasized that as an area develops and the price of land rises, the lot size (or land/nonland factor input ratio) of newly built units declines. Since units are durable, as development occurs, units of different density exist side by side. The older units display factor proportions which no longer reflect the least-cost technology, once factor prices have changed (generally with higher relative prices of land). That is, these units are not of the type that would be built in their place if all the development occurred in the present; or, looking at the issue from the other side, these units would be replaced with units which economized more on land if they were to wear out and fall down.

Conversion supply is accomplished, as is new construction, by the combination of land, labor, capital, and materials inputs. Conversion supply differs from new construction in that certain of the inputs, land and some of the capital, are already in place in a given quantity and form. Converters do not deal in the market for land, thus they respond to a set of signals different from those faced by new suppliers. Owners (or potential purchasers of existing property) compare the operating costs and revenues of the current use with the incremental capital costs (and demolition costs) and operating costs and revenues of uses to which the property could be converted (or replaced with after demolition). Because incremental costs are smaller for conversion than demolition-new construction, less disequilibrium is required to elicit the former than the latter supply response.

In the aggregate (that is, adding up over the decisions by individual suppliers) the most important determinant of conversion-demolition supply activity in a zone is the stock and type of housing units available. In addition, it is important how far "out of equilibrium" that stock is, how much demand for housing in the area has risen since the units were put in place. Increased demand, expressed per unit area, encourages more intensive uses of the area, that is, the production of more housing units on the given land. (Conversion will occur when output price times the new q minus annual incremental capital and operating costs is greater than output price times the old q .) Thus in a rough sense, we would expect more conversion activity (whether adding or subtracting units) in old units than new, because the old units are less well-adapted to current demand conditions. In addition, worn-out units, whether old or not, are most likely to be demolished, since current returns are not as high. Demolition activity thus reflects the need for normal replacement as well as radical conversion. "Radical" conversion, that is, demolition for replacement with a very different kind of structure, is more costly than building the structure on vacant land, and hence is undertaken only when the current structure is very far out of equilibrium and when there is very little vacant land (these two conditions occur together not coincidentally but rather because of the way the land market operates).

In addition to the existing stock and its current appropriateness, many of the same local conditions which affect new construction also affect conversion-demolition activity. High housing unit vacancy rates are a signal of excess supply in the market (and for the individual supplier with a vacant unit mean that there is no current return to be foregone

by changing the property use). Price changes act in much the same way, except that as a reflection of the rate of price change for both the origin and destination types it may not indicate the direction of conversion. Government programs such as urban renewal and public housing have direct impacts through land-clearing demolition and various kinds of subsidies to rehabilitation or alteration activity, and through these direct impacts may also affect decisions made by competing private suppliers in the same zone. Zoning, where it takes the form of minimum lot sizes, presumably inhibits the conversion of single unit structures into more than one unit, although often such zoning is enacted to control future development of open land rather than imposing restrictions on existing units.

The results of estimating conversion-demolition equations are shown in Table 2. In each case, the dependent variable is the net decade change in units of that structure type per acre not due to new construction. The dependent variable and independent variables relating to housing stock (old stocks, deteriorating stocks, public housing) are divided by total acres to control for the effects of arbitrary differences in area on the amount of housing supply activity taking place.

The very strong importance of existing stocks is well documented in Table 2. In each equation, the deteriorating stock is highly associated with demolitions. Old stock accounts for much of the conversion activity, the general direction being to increase densities, although a small share of multi-family units may be changing into singles. New construction of housing in areas without much vacant land (measured by $NEW\ TIGHT = NEW\ TOTAL / VACANT\ ACRES$, treated as endogenous) contributes significantly to demolitions

Table 2

CONVERSION-DEMOLITION SUPPLY EQUATIONS
 (Asymptotic standard errors in parentheses)

N = 89

	CONV SINGLE	CONV MULTI	CONV APART
CONSTANT	.0209 (.0673)	.0308 (.0773)	.0238 (.110)
Δ PRICE (endogenous)	.181 (.0893)	-.111 (.100)	-.179 (.145)
VAC RATE ₆₀	-.0211 (.0160)	-.0161 (.0176)	.0203 (.0223)
Δ VAC RATE (endogenous)	.00760 (.0195)	-.0513 (.0223)	.0353 (.0274)
OLD SINGLE ₆₀	-.189 (.0417)	.153 (.0345)	.0530 (.0427)
OLD MULTI ₆₀	.00997 (.0129)	.0784 (.0178)	.0211 (.0182)
OLD APART ₆₀			.310 (.00935)
DETER SINGLE ₆₀	-1.25 (.149)		
DETER MULTI ₆₀		-.977 (.112)	
DETER APART ₆₀			-1.92 (.0533)
MLS ZONING	-.000540 (.000527)	-.0000147 (.000567)	.000709 (.000689)
PUBLIC HOUSING		.0130 (.156)	.995 (.139)
LEASED PUB HOU		-.826 (.487)	-3.94 (.567)
NEW TIGHT (endogenous)	-.000509 (.0000903)	-.000740 (.000129)	
R ²	.9183	.9523	.9874
F-statistic (degrees of freedom)	113. (8,80)	156. (10,78)	612. (10,78)

of singles and multis. NEW TIGHT is not included in the apartment equation because apartments are less often torn down to make room for new units. This is both because apartments are already more intensive uses of land and because demolition costs are higher for such structures.

The aggregate data we have suggests that most (three-quarters) of the changes in the single stock measured by CONV SINGLE are demolitions (CONV SINGLE is negative for every city, town and district in the sample). Thus is it not surprising to see a significantly positive sign on price in the CONV SINGLE equation. Where returns are rising, existing uses are not abandoned. Similarly, where vacancy rates are high, more demolitions occur. In the other equations, the "CONV" activity is a mixture of conversions (in and out) and demolitions, and the price change coefficients are not significantly different from zero.

Zoning appears insignificant in all the equations, suggesting that zoning is more effective with regard to new construction. The other government policy tool, public housing, has a strong impact on conversion-demolition, especially of apartments. It appears that the more conventional forms of public housing, in which subsidies are provided for construction or rehabilitation, have a positive effect on the number of apartment (and multi-family) units, but that the leased public housing program discourages augmentation of the stock through conversion, or encourages demolitions. However, it should be noted that the statistical methods used cannot distinguish between the effects of the public housing programs and the housing conditions which make a jurisdiction adopt the public housing approach to solving their housing problems.

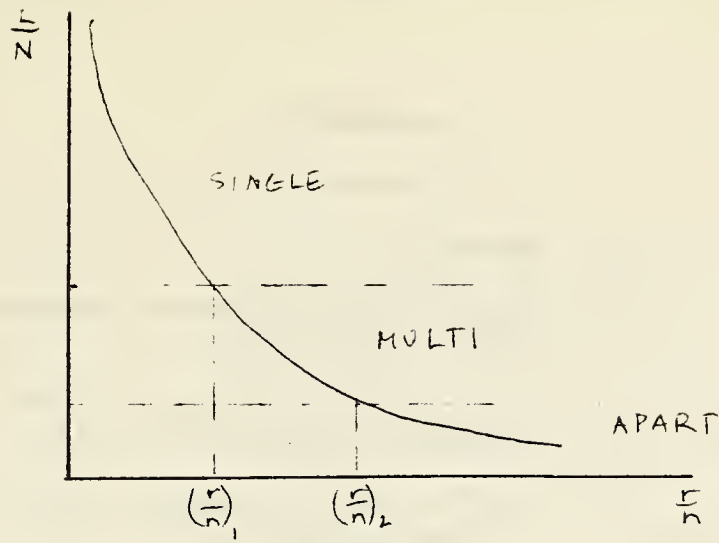
V. Summary

This has been a long paper. In concluding, we wish merely to note the special features of our approach and the chief thrust of our findings. Demand and supply relations for housing units have been derived and estimated using simultaneous equation econometric methods. The supply functions determine changes in different numbers and types of housing structures in the different zones, the demand functions determine the zonal distribution of the population partitioned by three income groups. Through price and vacancy rate changes, supply and demand jointly determine the location of households and housing structures.

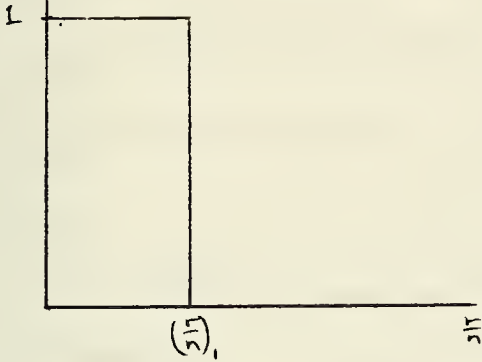
The demand relations model the decadal change in the proportion of each income group locating in each zone as a function of zonal attributes, accommodation prices and vacancy rates. These zonal attributes can broadly be described as structural attributes, social-environmental attributes, public service and tax rate variables and accessibility attributes. Our results suggest that different income groups have different relative tastes for these attributes. Two supply modes are treated separately - new construction and conversion/demolition. Decade changes in new units in any zone are a function of expected revenue changes (as reflected in price changes and vacancy rates) and expected costs, largely differential availability and land costs, as reflected in initial vacant acres, and minimum lot zoning. The composition of new construction in terms of structure types is determined largely by land prices which indicate differing land-capital ratios. Decade changes in zonal units through conversion/demolition are largely a function of the same expected revenue measures,

and cost measures that reflect the number of existing structures of different type, age and condition in the zone which are available for inexpensive conversion or ripe for demolition.

Our econometric estimations, by 2SLS, generally gave results that were encouraging. The overall fits were reasonable and the signs and patterns of relative magnitude of coefficients across structure type and supply mode on the supply side, and household type on the demand side are generally consistent with a priori expectations. Several variables do show puzzling results, and our present ongoing work is attempting to deal with problems exposed in the first stage of our study reported here.



$\frac{\text{NEW SINGLE}}{\text{NEW TOTAL}}$



$\frac{\text{NEW APART}}{\text{NEW TOTAL}}$

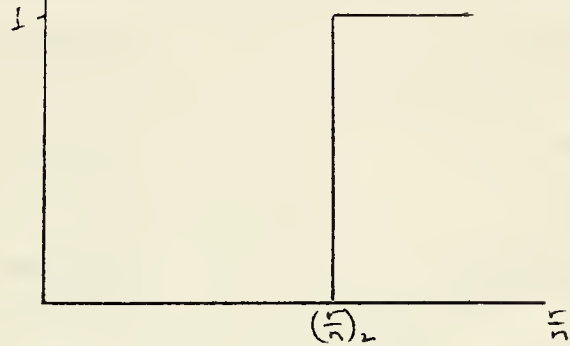
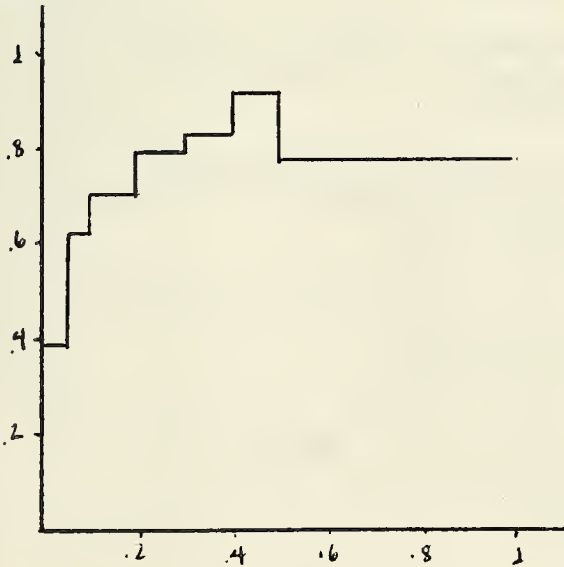


Figure 1

$\frac{\text{EW SINGLE}}{\text{EW TOTAL}}$



$\frac{\text{NEW APART}}{\text{NEW TOTAL}}$

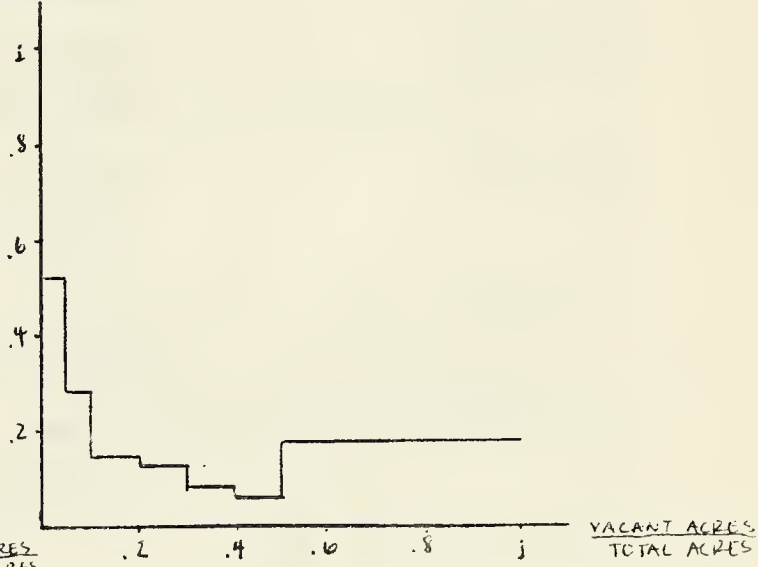


Figure 2

Appendix

Variable List

SYMBOLIC NAME	VARIABLE
LOW	The # of family households earning less than \$7000 in 1970 dollars.
MIDDLE	The # of family households earning between \$7000 and \$15,000 in 1970 dollars.
HIGH	The # of family households earning over \$15,000 in 1970 dollars.
SINGLE	# of single family housing units, divided by total acres.
MULTI	# of multi-family housing units, divided by total acres.
APART	# of apartment units, divided by total acres.
TOTAL	Total # of housing units.
NEW SINGLE	The number of single units in existence in 1970 which had been built since 1960.
NEW MULTI	The number of multi-family units in existence in 1970 which had been built since 1960.
NEW APART	The number of apartment units in existence in 1970 which had been built since 1960.
NEW TOTAL	All units in existence in 1970 which had been built since 1960.
CONV SINGLE	The 1960 to 1970 change in stock of single units due to conversions, retirements, and demolitions, per acre.
CONV MULTI	The 1960 to 1970 change in stock of multi-family units caused by conversions, retirements, and demolitions, per acre.
CONV APART	The 1960 to 1970 change in stock of apartment units caused by conversions, retirements, and demolitions, per acre.
CONV TOTAL	The change from 1960 to 1970 in the total # of housing units, which is not attributable to new construction.

Variable List

SYMBOLIC NAME	VARIABLE
OLD	The percent of 1960 units that were built before 1930.
LARGE	The percent of a zone's units which have 7 or more rooms.
BATHROOMS	The percentage of a zone's units which have greater than one bathroom.
DETERIORATE	The percentage of a zone's units which are deteriorating.
POP DEN	Population ÷ residential, vacant and recreational acres.
BLACK	The percent of a zone's population that is nonwhite.
CRIME	FBI comprehensive crime rate.
WELFARE	% of households on welfare.
VACANT ACRES*	The # of acres of land which are vacant.
MLS ZONING	The % of a zone's residential and vacant land zoned for lot sizes larger than 25,000 square feet.
SEWER	Sewer availability: the % of population served by public sewers.
PT RATIO	Pupils/teacher high schools.
EFF TAX	Effective property tax rate.
JOB ACC	General road accessibility to employment.
JOB ACC ^j	$= \sum_{K=1}^{89} X_K C_{jK}$
	where
	C_{jK} = travel time from zone j to zone K X_K = employment of income type (either HIGH, MIDDLE, or LOW) in zone K relative to S.M.S.A. total employment of that income type
RESIDENTIAL ACRES*	The number of acres devoted to residential uses.

Variable List

SYMBOLIC NAME	VARIABLE
TOTAL ACRES*	The number of acres of land in a zone = total area minus acres of open water.
HIGHWAY	Highway availability index = $(3 * \text{No. limited access superhighways} + 2 * \text{No. 4-lane highways} + 1 * \text{No. 2-lane highways.}) / \text{total acres in zone}$
VAC RATE	Overall housing unit vacancy rate = $(\text{units vacant for rent} + \text{vacant for sale}) \div \text{occupied and vacant units.}$
ΔPRICE	Housing price 1970 \div housing price 1960.
OTHER ACRES*	Acres of land devoted to manufacturing.
OPEN	Estimate of fraction of zone's area which is vacant and not subject to minimum lot size zoning = $UZ * VACP.$
PZ	The fraction of a zone's area zoned for minimum lot sizes greater than 25,000 square feet = $MLS \text{ ZONING} \div 100.$
UZ	The fraction of a zone's area <u>not</u> zoned for minimum lot sizes greater than 25,000 square feet = $1 - PZ.$
A	A zero-one dummy; A = 0 when town's zoning code prohibits apartments.
OLD SINGLE	An estimate of the number of single units more than 30 years old, per acre = $SINGLE * OLD.$
OLD MULTI	An estimate of the number of multi-family units in structures more than 30 years old, per acre = $MULTI * OLD.$
OLD APART	An estimate of the number of apartment units in structures more than 30 years old, per acre = $APART * OLD.$
DETER SINGLE	An estimate of the number of single family units which are deteriorating, per acre = $SINGLE * DETERIORATE.$
DETER MULTI	An estimate of the number of multi-family units which are deteriorating, per acre = $MULTI * DETERIORATE.$

Variable List

SYMBOLIC NAME	VARIABLE
DETER APART	An estimate of the number of apartment units which are deteriorating, per acre = APART*DETERIORATE.
PUBLIC HOUSING	The number of "conventional" and "turnkey" (federal) public housing units in a zone in 1974, per acre.
LEASED PUB HOU	The number of units of federally-sponsored leased public housing in a zone in 1974, per acre.
NEW TIGHT	The number of new housing units built during the decade per acre of vacant land initially available = NEW TOTAL ÷ VACANT ACRES. This measures the likelihood of demolition activity as a means of making land available to new construction.
VACP	Fraction of zone's land which is vacant = VACANT ACRES ÷ TOTAL ACRES.

The seven vacant land percent dummy variables are defined as follows:

- V1 = 1 if VACP < .05, 0 otherwise
- V2 = 1 if .05 ≤ VACP < .10, 0 otherwise
- V3 = 1 if .10 ≤ VACP < .20, 0 otherwise
- V4 = 1 if .20 ≤ VACP < .30, 0 otherwise
- V5 = 1 if .30 ≤ VACP < .40, 0 otherwise
- V6 = 1 if .40 ≤ VACP < .50, 0 otherwise
- V7 = 1 if .50 ≤ VACP, 0 otherwise.

* The 1960 acreage data is derived from a 1963 land use survey; the 1970 acreage data is derived from a 1972 land use survey.

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MEMORANDUM

BASEMENT

Date Due

OCT 14 '76	JUN 6 '76	
OCT 16 '76	DEC 4 '78	
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MAR 17 '77	JAN 04 '80	
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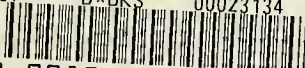
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