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Chapter Three

Simultaneous Estimation of the Supply and Demand for Housing Location in a Multizoned Metropolitan Area

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INTRODUCTION

In this chapter we report 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 there. 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 business activity over the area.

This model was designed for use in 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 judgments can be made. In order to satisfy this objective, it is important to formulate a behavioral model that incorporates a rich choice of meaningful policy alternatives.

Each of the three submodels incorporates its own set of policy

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issues, which can be examined in isolation. In this study we present preliminary results only for the housing location submodel, but results from other submodels are described in Engle (1974a, 1974b, 1974c) and Engle et al. (1972). Because this is only a first stage in our efforts to formulate and estimate the complex relationships determining household location, we do 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 to suggest 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 that 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: construction of new units and conversion (comprising physical modification, retirement, and demolition) of existing ones. 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 type of component and among 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 differ in their effect in attracting the spectrum of household types.

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 (de Leeuw, Struyk, Marshall 1973; Ingram, Kain, Ginn 1972), 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 (Wheaton 1974; Harris, Nathanson, Rosenberg 1966), based on the equilibrium assumptions underlying the bid rent model, estimate closed systems for demand behavior but do not integrate this with supply and have some unattractive features; for example, vacancy rates are not included.

Our approach is to formulate a model that can be estimated econometrically from observed aggregate data. The model is based on appropriate and often testable behavioral assumptions concerning 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 the latter 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 its supply. 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 divided the Boston metropolitan area into 89 zones: Boston itself is divided into 14 Boston Redevelopment Authority districts, and to this we added 75 surrounding cities and towns.

The location of any particular accommodation specifies many components of the housing package. For demanders the important dimensions of a location 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, quality, and cost of available public services (parks, schools, health and sanitation services, streets, tax rates), and the accessibility to desirable destinations in the rest of the SMSA. For suppliers the location suggests prospects for revenues and costs associated with the provision of additional units of different types, since each location is characterized at a given time by specific prices and vacancy rates, on the one hand, and vacant land availability, zoning constraints, sewer systems, and stocks available for conversion, on the other.

The selection of political jurisdictions to represent locations is important. We aggregate to, but not beyond, the level of the political jurisdiction both because of data availability and because we believe the public service-tax component of the locational dimension is especially important to both the demand and supply sides. In addition, code and zoning regulations stem from the local governments and constitute 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 government 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 zones is traced in terms of occupancy by low-, middle-, and high-income-family households. These three categories of demand serve to allocate the urban population over space in a partition that is not only interesting in itself because of its relevance to many socioeconomic problems and public policy issues, but is in 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 our household allocation submodel.

The three household groups are seen as competitors for the scarce resource of housing accommodations. Presumably all groups would prefer to locate in attractive zones with good public services and high accessibility. However, because of the heavy competition for the limited number of accommodations in such zones, prices of units there tend to rise 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 structural type—single-family units, units in multiunit structures (two to four units per structure), and units in apartment structures (more than five 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 structural type.

The geographic partition of demand and supply in effect treats the market for housing accommodations in each zone as a separate housing submarket. 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 types 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 enough or far enough to clear the market in a reasonably short time. The market's immediate and moderate-term responses to excess demand are registered partly by movements in the vacancy rate. For example, in a tight market, prices may not rise far enough to choke off sufficient demand to clear the market (inclusive of a "normal" vacancy rate), so vacancy rate falls below the normal level. Alternatively, in periods of slack demand prices 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. First, the figure obtained by subtracting the vacancy rate from unity reflects the probability that an additional unit in the zone will be sold or rented; second, the rate points to future adjustments of price within that zonal market.

HOUSING DEMAND

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[1] accessibility from the zone to other desirable destinations in tne 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 percent of the units in a zone that are large, old, 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 that have mostly large units, leading to some demand in a zone by household types that 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 that contain a relatively high proportion of luxury units, because the zonal average indicates both their probable own accommodation choice and the probable character of their neighbors.

A second class of components refers to the social environment of the zone, i.e., the nature of the residents and of their zonal occupancy. We characterize the former by the percent of the zonal population that is nonwhite and the percent 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 local public-sector 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 variables such as these 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 accessibility of a zone to be inversely related to the anticipated real cost of travel by residents of that zone. For each zone the expected real cost to a destination depends upon the location of the latter and the nature of the transportation network. Different household types have different destinations and different modal choices. The measurement of accessibility 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. Accordingly, in order to capture some sense of this complexity we have constructed a number of accessibility indexes: a general job accessibility index by income class in which destinations and their probable importance in measures of the relative frequency of trips, distance, 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, but not exclusively so, by the nature of the package available in each zone. The choices depend as well on the income level of the household which simultaneously determines the preferences for different housing package configurations and the desirable tradeoffs between housing and nonhousing commodities. Finally, the choices depend on the prices of the different housing packages available, including the cost of finding a suitable unit. In summary, an array of different zonal housing packages is available to any household. The packages differ in their attractiveness, which depends partly 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 that is located in each zone. We have a separate zonal location demand function for each of the three income classes—high, middle, and low—into which we partition family households. An observation involves use of the set of attributes and relative prices of a given zone as explanatory variables to predict the percent of each SMSA family income class that 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. It indicates that once the demand and supply equations are solved—and that is what takes place in the real world process of competition for scarce attractive housing packages—low-income groups get what is left over because groups with more market power have already taken their pick.

In our structural model, the tradeoff between price, zonal search costs, and the attributes of the zonal housing package determine which income group finally locates in a particular zone. Coefficients on zonal attributes for the different household groups reflect relative group preferences for the attribute combined with the group's relative willingness to exchange money for preferred housing accommodations. It is these differences in the pattern of coefficients among income classes which lead to that critical characteristic of U.S. metropolitan areas, the sharp socioeconomic 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^i_j. 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:

$$P^i_j = g^i(X_j) \tag{3-1}$$

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, that 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 group offering the next highest bid, and the market price will be that lower price of the group of second highest bidders 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 other zones where they are either highest or second highest in zones that have excess accommodation. Shortages in the first zone will force the group to raise its whole set of bid prices in its competition to allocate first and second choices among its members. 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 that would have been the first choice of a given group if it had had enough units available to keep the price down, may drop to second or lower choice if it has a smaller number of units permitting the price to be considerably higher.

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:

$$\text{Number of occupants in zone } j \text{ from group } i = f(P_j, P_j^i) \qquad (3\text{-}2)$$

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 (3-2)) should be a step function: for $P_j = P_j^i$, the whole group locates in j; for $P_j > P_j^i$, no member of the group locates there.[2] In a perfect market, the long-run supply response 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, which include density and other nonstructural zonal attributes, can be supplied at constant costs) each zone will be homogeneous with respect to users.

Our treatment diverges somewhat from this procedure. 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 $P_j \leqslant P_j^i$ for user groups. Second, we do not assume that all users are in their long-run equilibrium. The high cost of changing occupancy prevents 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:

$$\text{Number of units available in zone } j = \sum_i \text{(number of households of group } i\text{)} + \text{vacant units} \qquad (3\text{-}3)$$

As noted earlier, we assume that price does not adjust rapidly to market changes; so vacancy rates represent a residual adjustment and, together with price, act therefore as a pair of indicators of the current state of the market; furthermore, 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 there.

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 is

$$\text{Number of occupants in zone } j \text{ from group } i = f^*(P_j, VR_j, P_j^i) = f^*[P_j, VR_j, g^i(X_j)] \quad (3\text{-}4)$$

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 the price level prevailing there. It also depends, however, upon the prices, search costs, and attributes of other zones that are close substitutes for the given zone. In general, the demand in any zone must depend upon all the prices, costs of search, and housing package attributes in all other zones. Unfortunately, the strength of the cross elasticities varies endogenously. As a simple first solution, the price, search costs, and attributes of each zone were taken relative to the SMSA average for each variable.[3]

The price variable is designed to be the price per unit of a standard accommodation in a zone. Using actual sales data, price indexes for each zone were constructed by a regression method described in Bailey, Muth, Nourse (1963) and illustrated with the same data in Engle (1977). 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.[4]

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

$$D_z^y/\overline{D}^y = D^y\,(A_z^1/\overline{A}^1, A_z^2/\overline{A}^2, A_z^3/\overline{A}^3, A_z^4/\overline{A}^4, P_z/\overline{P}, V_z/\overline{V}) \quad (3\text{-}5)$$

where D_z^y is the number of households of income y who demand location in zone z, and D represents the SMSA average. A^1, A^2, A^3, A^4 are the vectors of components of the zonal housing package corresponding to structural and land attributes, social environment, public service tax, and accessibility, as described earlier; P_z is the zonal price; and V_z, the initial zonal housing unit vacancy rate, which is a measure of search costs; and A^{-1}, A^{-2}, . . . , V are the SMSA means. 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 (TSLS) was used to estimate the coefficients of the 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 ($\Delta POPDEN$), the change in the percent nonwhite ($\Delta BLACK$), and the change in the percent of households on welfare ($\Delta WELFARE$), were all treated as endogenous.

The estimated coefficients for the *LOW-*, *MIDDLE-*, and *HIGH*-income family household groups are shown in Table 3-1, with all the variables defined in detail in Appendix 3A. As noted earlier, the sample consists of the 89 zones of the Boston SMSA. Asymptotic standard errors and other diagnostic information are presented for each equation.

These preliminary results display an encouraging degree of consistency with theoretical expectations. The a priori expectations for the signs of the coefficients are displayed in Table 3-1. In 80 percent of the cases, these are satisfied and in only two cases are the expectations rejected at the 95 percent level for a one-tailed asymptotic test. The coefficients themselves are elasticities: a coefficient of 0.5 in Table 3-1 means that if the zone were to increase its relative supply of the attribute by 1.0 percent, the zone's share of that income group would increase by 0.5 percent.

All three estimated coefficients in the price change variable, $\Delta PRICE$, are negative—as economic theory would lead us to believe a priori. The standard errors of this variable, however, are 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 other 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 members 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 a view to capturing future capital gains.

Each zonal housing market is viewed as adjusting itself through both price and quantity variations in all but the very long run. Excess zonal demands or supplies are registered by movements in both the

Table 3-1. Estimates of Household Demand Equations by Two-Stage Least Squares[a] (figures in parentheses are asymptotic standard errors)

Symbol	Type	A Priori Expected Sign: Low	Middle	High	Estimated Coefficients: Low	Middle	High
$\Delta PRICE$	Endog.	–	–	–	–.49 (.35)	–.20 (.26)	–.19 (.58)
$VACRATE_{60}$	Exog.	+	+	+	–.06 (.06)	.11* (.04)	.24* (.09)
$\Delta BATHROOMS$	Endog.	+	+	+	–.01 (.10)	.26* (.08)	.74* (.17)
$\Delta LARGE$	Endog.	+	+	+	.02 (.19)	–.30* (.15)	–.41 (.32)
OLD_{60}	Exog.	–	–	–	–.09 (.14)	–.20* (.11)	–.62* (.23)
$\Delta POPDEN$	Endog.	–	–	–	–.02 (.03)	–.02 (.03)	–.08 (.06)
$BLACK_{60}$	Exog.	?	–	–	.05* (.03)	–.05* (.02)	–.09* (.04)
$\Delta BLACK$	Endog.	?	–	–	.08* (.03)	–.06* (.03)	–.14* (.06)
$\Delta WELFARE$	Endog.	+	–	–	.05 (.06)	–.07* (.04)	.04 (.09)
$CRIME_{70}$[b]	Exog.	–	–	–	–.04 (.04)	–.03 (.03)	–.17* (.07)
$\Delta EFFTAX$	Exog.	–	–	–	–.08 (.12)	–.02 (.09)	–.21 (.20)
$\Delta PTRATIO$	Exog.	–	–	–	–.31* (.12)	–.01 (.09)	–.07 (.20)
$\Delta JOBACC$	Exog.	–	–	–	–.47* (.22)	.37* (.16)	.27 (.38)
$\Delta HIGHWAY$	Exog.	–	–	–	–.002 (.07)	–.05 (.05)	–.23* (.12)
Constant					.63 (.33)	.37 (.25)	.83 (.55)
R^2					0.39	0.50	0.52
SSR					2.13	1.24	5.87
SE					0.17	0.13	0.28

Notes

R^2 = coefficient of multiple determination.

SSR = sum of squared residuals.

SE = standard error of the regression.

*Significant at 5 percent level in one-tailed asymptotic test.

[a]The instruments used with the endogenous variables were the exogenous variables of the supply equations and the 1960 predetermined values of the endogenous variables. Except as noted, all variables are 1960-1970 changes in ratios to the SMSA means.

[b]The 1970 level relative to the SMSA was used because 1960 data were lacking.

zonal price and the zonal vacancy rate. The zonal vacancy rate for the beginning of the decade, $VAC\ RATE_{60}$, is included in the demand equations. The $VAC\ RATE_{60}$ coefficients increase in size from the *LOW* equation, in which the coefficient is insignificant and negative, through the *HIGH* one. This is consistent with the higher opportunity costs of search for high-income households. In the equations for *HIGH*- and *MIDDLE*-income families, the estimated coefficients on $VAC\ RATE_{60}$ are positive, as we expected on the basis of a priori economic theory concerning the costs of search, and they are statistically quite significant.

Four structural attributes were utilized in these preliminary regressions: the percent of a zone's units that are large (7 rooms or more), $\Delta LARGE$; the percent of a zone's units that are over thirty years old, OLD_{60} the percent of a zone's units that have more than one bathroom, $\Delta BATHROOMS$; and the population density $\Delta POPDEN$. The coefficients on $\Delta BATHROOMS$ increase in size from the *LOW* to the *HIGH* equation, supporting the a priori expectation of a much stronger preference for more luxurious and larger units by higher-income families. The coefficients in *MIDDLE* and *HIGH* are not only large in absolute size, but are also statistically very significant; the one in *HIGH* (0.74) is, in addition, the most economically and statistically significant coefficient in the *HIGH*-income equation.

The coefficients on OLD_{60} are all negative, consistent with our a priori assumption that households prefer newer units, ceteris paribus; and the values increase from *LOW* to *HIGH*, again as expected. The coefficients in *MIDDLE* and *HIGH* are statistically fairly significant and are, in addition, among the largest in absolute size. Indeed, the variables characterizing the structural components of the zonal housing package plays a very important role in our estimated demand equations.

Population density, $\Delta POPDEN$, also proved to be an important variable: all the signs are negative, as expected, and increase in absolute size from the *LOW* to the *HIGH* equation, supporting our hypothesis that the higher the family's income, the stronger its preference for low density. This observed preference of high-income families for space partially explains the presence of the high-income suburban ring so common in U.S. metropolitan areas.

All four of the social environmental attributes were found to be significant in one or more of the equations. The percent of nonwhite households in a zone was included to capture the preference of whites to live segregated from nonwhites. Both the percent nonwhite at the beginning of the decade, $BLACK_{60}$, and the change in the percent nonwhite, $\Delta BLACK$ (treated as endogenous), were included, and their estimated coefficients turned out to be statistically significant in all three equations. The signs on both variables were positive in the equation for *LOW*-income families, reflecting the high proportion of nonwhites in this group: the majority of nonwhite households in the Boston SMSA are of low income.[5] The coefficients of both variables are negative in the *MIDDLE* and *HIGH* equations, strongly confirming the preference for segregation by Boston SMSA whites; and the larger negative coefficients on both variables in the *HIGH* equation imply that this preference is more intense among higher-income whites. It is noteworthy that the preference appears quite strongly even when we control for the higher welfare population, higher tax rates, poorer schools, and higher crime rates of the central city—conditions often cited as reasons for the flight by whites to the segregated suburban communities.

Approximately 65.6 percent 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, $\Delta WELFARE$, would be positive in the *LOW* equation. The results 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 $CRIME_{70}$ obtained in all the estimated equations.

The local public service variables also proved significant. The importance of the quality of the local public schools to the zonal housing package is supported by our results. All three estimated coefficients on $\Delta PTRATIO$ were negative, as expected, as were those for local effective tax rates. High-income families seem to be the most sensitive to (or most adept at avoiding) high relative tax rates.

A priori, we expected that households at all income levels would prefer more accessibility to less. The higher the relative value of the general job accessibility index, $\Delta JOBACC$, the lower 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 incur the highest opportunity cost for their time spent in commuting. Therefore, the expected pattern of the size of the coefficients on $\Delta JOBACC$ was uncertain. As can be seen from Table 3-1, low-income families do prefer locations that are highly accessible to their jobs. The positive coefficients 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 suggest that the negative externalities generated by highways crossing a zone are important. The absolute size of the coefficients increases with the income level of the household, as expected, 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. To evaluate this interpretation, more recent work is designed to disclose whether the highway variable reflects negative externalities mostly, or some composite of such externalities and facets of accessibility.

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 structural type (in terms of units per structure). In effect, we are modeling the behavior of two basic types of housing supplier: builders of new units and owners of existing ones. Conversion supply is given 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 other 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 structural 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 produced in a zone will therefore depend on the price and possibly the quantity of the factors available in the zone, and on 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 output prices and in factors relating to land and to conversion of existing structures.

We begin our exposition of the housing supply model with a discussion of new construction and of how the land market interacts with new-supply decisions. Then the determination of the structural 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.

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 of the literature on urban land use and is important in our housing supply model as well. Alonso (1960, 1965) 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 the allocation of land among user types. The starting assumption of the models is 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 then 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 locational 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. Therefore, 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). As a result, we observe that the curves of land prices and land use densities predicted by land use models decline as we move away from the center and the shares of vacant land increase. As population or income in an urban area grows over time, the derived demand for land in all uses increases. As a result, more and more land is absorbed into the urban fringe, *and* vacant land within the developed urban area declines. The metropolitan area develops simultaneously out *and* up, extensively and intensively.

In the context of this housing supply model, each "location" to which the analysis is applied is a city, town, 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 in which the price of land is 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 who are in the market for land. Rather, this speculation 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 production function having constant returns to scale:

$$Q = Q(L, N) \tag{3-6}$$

where Q is total housing units produced and L and N are the amount of land and nonland inputs, respectively. This production function implies a relationship between output price and factor prices:

$$p = p(r, n) \tag{3-7}$$

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. Consequently, the land input per housing unit is a function of the price of land (or really the factor price ratio):

$$L/Q \equiv m = m(r/n) \text{ or } L = m(r/n)Q \tag{3-8}$$

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

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

$$r = r(V/T) = r(\text{v}) = r[(T - L - J)/T] \tag{3-9}$$

where T is total land area in a town; J, land area previously developed; V, the amount vacant; $v \equiv V/T$. For simplicity this function is often assumed to have a constant elasticity.

If all these functions are well-behaved, then from (3-7), (3-8), and (3-9) we can derive 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:

$$p = f(Q/T) \text{ or } Q/T = s(p) = f^{-1}(p) \qquad (3\text{-}10)$$

Q/T can be thought of as gross residential density or, more simply, as a quantity of output along a supply curve that 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: the responsiveness of lot size (and hence total derived demand for land at any output level) to changes in the price of land and the responsiveness of the price of land to changes in the quantity developed (or demanded) by housing producers.

Taking percent derivatives of supply equation (3-10) at a point, we obtain the relationship between output prices and quantities given by Muth (1974, p. 228):

$$\frac{dQ}{Q} = \frac{k_N \sigma + e_L}{k_L} \frac{dp}{p} \qquad (3\text{-}11)$$

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 for new construction. The speculation model of vacant land release suggests that the price elasticity of the residential land supply varies directly with the supply of 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 $\sigma < 1$ (Muth 1969, pp. 82-83 and 315, offers support for this hypothesis) the factor shares are a function of factor prices, and share of land 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, the implication of Equation (3-11) is that there is 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 lower 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.

An additional element that varies among zones and directly affects the new housing production function is the amount of land in other uses. It has the same effects on the price and elasticity of the supply of land as does the amount of land consumed by housing producers. Housing producers in a town with increasing "other land use" face higher land prices, ceteris paribus, according to (3-9). Thus we need to include in (3-11) a term reflecting any shifts in the land supply curve during the decade. (Differing initial conditions are captured by the initial supply elasticity of land.) The appropriate form for this equation has also been derived by Muth (1974) and is

$$\frac{dQ}{Q} = \frac{k_N \sigma + e_L}{k_L} \frac{dp}{p} + e_{L,J} \frac{dJ}{J} \tag{3-12}$$

where $e_{L,J}$ is the elasticity of supply of L with respect to J (other land use), and dJ/J is 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 assumé a constant elasticity in (3-9) the second term in (3-12) simplifies to dJ/L.

The foregoing are not the only factors that impinge on the supply of new housing in a metropolitan area. Because of the lags that characterize adjustments in housing market price and quantity and the unitary character of purchases or leases (one household to one housing unit), vacancy rates are an important adjustment mechanism in equating housing supply and demand. 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 100 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 subareas 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 subareas, or the effect may actually be to restrict some kinds of housing production in the zone. If producers are prevented from using the land-per-unit ratio of their choice, their profits may be reduced, and one would expect less housing production. Zoning regulations on minimum lot size, for example, when binding, reduce the amount of effective land available to producers.

From (3-11) and the additional factors discussed above, we derive a supply equation for new construction to be estimated econometrically:

$$\frac{dQ}{Q} = a_0 + a_1 [f(v) \frac{dp}{p}] + a_2 \frac{dJ}{L} + a_3 \frac{d\ VAC\ RATE}{VAC\ RATE} + a_4\ OPEN + \epsilon \qquad (3\text{-}13)$$

where Q, v, p, J, and L are defined as above, $d\ VAC\ RATE/VAC\ RATE$ is the percent 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 that 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 and a_4 to be positive and a_2 and a_3 to be negative.

The supply relation was estimated using decadal percent changes in the number of housing units in a cross section of 89 Boston metropolitan area subregions. The equation is estimated by TSLS, with prices and vacancy rates treated 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; complete definitions of the variables are given in the appendix:

$$\frac{NEW\ TOTAL}{TOTAL_{60}} = \underset{(.0278)}{.116} + \underset{(.0116)}{.0713}$$

$$* \frac{VACANT\ ACRES_{60}}{RESIDENTIAL\ ACRES_{60}} \frac{\Delta PRICE}{PRICE_{60}}$$

$$- \underset{(.118)}{.172} * \frac{\Delta\, OTHER\ ACRES}{RESIDENTIAL\ ACRES_{60}} - \underset{(.0384)}{.125}$$

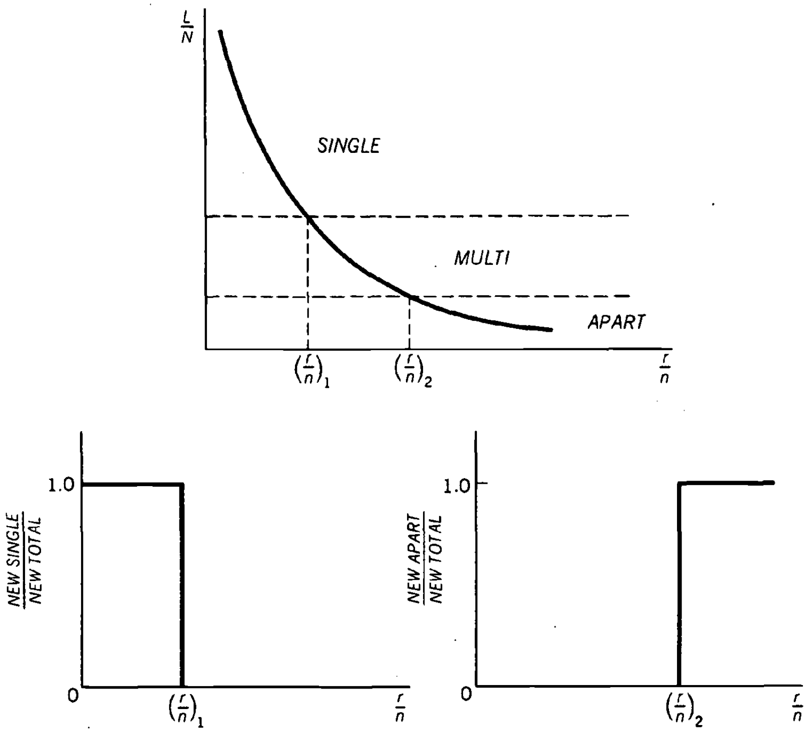
$$* \frac{\Delta(VAC\ RATE)}{VAC\ RATE_{60}} + \underset{(.106)}{.199}\ OPEN + e$$

The standard error of the regression = 0.13; R^2 = 0.4358. The overall fit of the equation is reasonable, the individual coefficients have small standard errors, and the signs are as expected. In particular, the t ratios on the price elasticity and vacancy rate are quite large.

The estimates imply price elasticities of new housing supply that range from 0.87 in the open suburbs to almost zero (0.0007) 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 that does not face zoning restrictions will lead to new construction.

Structural Types of New Construction

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 structural types in new housing. Where the price of land is higher (across zones or over time within a zone), a housing unit will be 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 structural types (and each structural type is built where its technology is most profitable), or one technology for all types, as long as that one 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 (3-8) 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 structural types in terms of a range of land-to-nonland input ratios, given any input price ratio, we would know the structural type of all new construction. This is illustrated in Figure 3-1.



Note: r = price of land input; n = price of nonland input; L = amount of land input; N = amount of nonland input. Other variables are defined in the appendix.

Figure 3-1.

However, when we actually observe the structural types of new construction in different zones in the metropolitan area, we do not see such unanimity as to the appropriate type for 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 types of structural response within a town when the decade is taken as a whole.

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

Third, historical and institutional restrictions interfere with the deterministic effect of land price on structural type. Zoning, neighborhood effects, and the timing of release of land parcels and their size (whether through demolition, lot splitting, or sales of vacant land) may make only one structural 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 problem of measurement or definition. The production function implies that the land-nonland ratio responds as a continuous function of the price of land (as depicted in Figure 3-1), that is, lot size decreases as the price of land increases. What we measure with our census data on structural type (single, multifamily defined as composed of two to four units, and apartments with five or more units per structure) only corresponds very crudely to a measure of land per unit or an input ratio of land to nonland. 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 structural type. However, rather than being an on-off switch between types, the relationship between land price and the distribution of structural types in new construction 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 choice of structural 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 a particular 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 plays a role in determining the technological feasibility of different structural types.

Zoning, cited above as one of the interferences between land price and structural type, is a local-government policy tool whose impact can be modeled more explicitly. Zoning regulations generally restrict housing producers' choices asymmetrically, 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 the case in which the town zoning code prohibits apartment structures; the apartment share of new construction is then expected to be zero, and the 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 minima for part or all of the residential (and vacant) area of a town. The variable is a measure of the percent of the town that 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 each structural type in total new construction. If minima apply in part of a town, singles will be built in that part and land price and sewer availability will determine what is built in the unzoned areas.

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

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

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 is

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

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

where PZ is the fraction of land zoned for lot sizes greater than 25,000 square feet, and UZ is 1.0 minus PZ, the share unzoned.

The fraction of decadal new construction that is single family and the fraction for apartment units (five or more units in the structure) are therefore modeled as functions of the price of land, zoning, and sewer availability. The share of new construction that is multifamily (two to four units in the structure) is the residual, that is, total new construction less singles and apartment units.

Land price is represented, 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 (*V*1 through *V*7), each of a range of values of the variable. It is discrete rather than continuous, because, as postulated earlier, land price is not a linear function of percent vacant, and even if it were, we would not expect the shares of new construction that are single or apartment units to be linear functions of land price.

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

$$\frac{NEW\ SINGLE}{NEW\ TOTAL} = \underset{(.0425)}{.958}\ PZ - \underset{(.00111)}{.00278}\ UZ{*}SEWER$$

$$+ \underset{(.119)}{.392}\ UZ{*}V1 + \underset{(.123)}{.618}\ UZ{*}V2 + \underset{(.109)}{.700}\ UZ{*}V3$$

$$+ \underset{(.110)}{.799}\ UZ{*}V4 + \underset{(.0854)}{.828}\ UZ{*}V5 + \underset{(.0881)}{.907}\ UZ{*}V6$$

$$+ \underset{(.0878)}{.768}\ UZ{*}V7 + e$$

$R^2 = 0.7921$; standard error of the regression = 0.157.

$$\frac{NEW\ APART}{NEW\ TOTAL} = \underset{(.00105)}{.00276}\ A{*}UZ{*}SEWER + \underset{(.112)}{.518}\ A{*}UZ{*}V1$$

$$+ \underset{(.117)}{.298}\ A{*}UZ{*}V2 + \underset{(.103)}{.145}\ A{*}UZ{*}V3$$

$$+ \underset{(.104)}{.130}\ A{*}UZ{*}V4 + \underset{(.0803)}{.0936}\ A{*}UZ{*}V5$$

$$+ \underset{(.0815)}{.0644}\ A{*}UZ{*}V6 + \underset{(.0779)}{.192}\ A{*}UZ{*}V7 + e$$

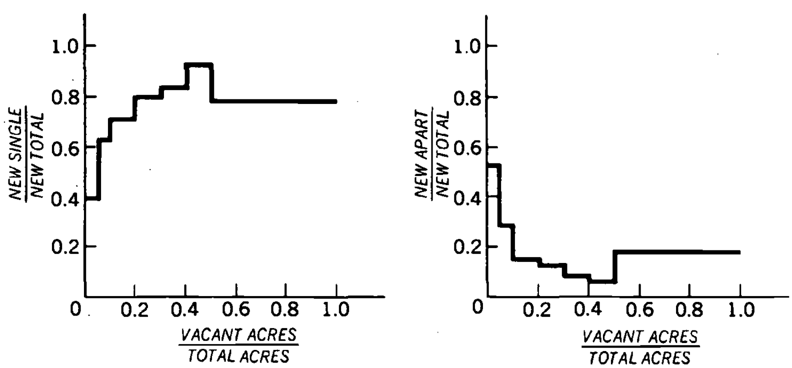
$R^2 = 0.7770$; standard error of the regression = 0.149.

The progression of coefficients across the categories is in the expected directions (increasing for singles, decreasing for apartments) except for the last category. In each case, the coefficient on *V7* (= 1 if fraction vacant ⩾ 0.5) is not significantly different in a statistical sense from that on *V6*. These coefficients are displayed graphically in Figure 3-2.

SEWER enters both equations as expected, implying that for each ten percentage points of sewer availability in a zone, an additional three percentage points of new construction are apartments, not singles, ceteris paribus. A *t* test of the coefficient on *PZ* in the *SINGLE* equation shows it is not statistically significantly different from unity, which is what the model predicted. The use of the zoning variables multiplicatively (both *UZ* and *A*) surpasses either their exclusion or their inclusion as a separate linear continuous variable by improving both the overall fit (higher R^2, lower sum of squared residuals) and the individual coefficients.

Conversion Supply

The second major means of housing stock adjustment is by changing existing housing units to provide a different quality or quantity of services. By 1970, over 10 percent of the 1960 Boston SMSA 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. 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



Note: See appendix for definition of variables.

Figure 3-2.

conversion-demolition is on changes in the number of housing units and their structural 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; it may be done in order to create open space 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 as 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 the factor input ratio of land to nonland) of newly built units declines. Since units are durable, as development occurs, units of different densities may be found 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 that location if all the development had occurred in the present; or, looking at the issue from the other side, replacement units would economize more on land.

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 structure could be converted (or by which it could be replaced). Because incremental costs are smaller for conversion than for demolition-new construction, less disequilibrium is required to elicit the former than the latter supply response.

In the aggregate (that is, adding up the decisions of the individual suppliers) the most important determinant of conversion-demolition supply activity in a zone is the stock and type of housing units available. The extent to which demand for housing in the area has risen since the units were put in place, i.e., the degree to which the stock is out of equilibrium, is also a factor. Increased demand, expressed per unit of 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 number of units in the structure minus annual incremental capital and operating costs is greater than output price times the old number of units.) Thus, in a rough sense, we would expect more conversion activity (whether addition or subtraction of units) in old units than in new, because the former are less well-adapted to current demand conditions. In addition, worn-out units, whether old or not, are most likely to be demolished, since their current returns are not as high as they would be on potential replacements. Demolition activity thus reflects the need for normal replacement as well as radical conversion. The latter, 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).[6]

In addition to the existing stock and its current appropriateness, many of the same local conditions that affect new construction also affect conversion-demolition activity. High housing unit vacancy rates are a signal of excess supply in the market. To an individual supplier, the significance of a vacant unit is that there is no current return to be foregone by changing the property use. Price changes act in much the same way, except that since they reflect the rate of price change for both the original and resultant structures, they 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 multi-unit types, although often such zoning is enacted to control future development of open land rather than to impose restrictions on existing units.

The results of estimating conversion-demolition equations are shown in Table 3-2. In each case, the dependent variable is the net decadal change in units of that structural 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 acreage to control for the effects of arbitrary differences in area on the amount of housing supply

Table 3-2. Conversion-Demolition Supply Equations (figures in parentheses are asymptotic standard errors; $N = 89$)

	CONV SINGLE	*CONV MULTI*	*CONV APART*
Constant	0.0444 (0.0685)	0.0596 (0.0785)	0.0122 (0.112)
$\Delta PRICE/PRICE_{60}$ (endogenous)	0.146 (0.0977)	−0.139 (0.106)	−0.200 (0.151)
$VAC\ RATE_{60}$	−2.33 (1.71)	−1.90 (1.87)	2.99 (2.40)
$\Delta VAC\ RATE$ (endogenous)	−0.560 (2.17)	−5.30 (2.46)	3.13 (3.10)
$OLD\ SINGLE_{60}$	−0.199 (0.0430)	0.148 (0.0353)	0.0598 (0.0447)
$OLD\ MULTI_{60}$	0.0151 (0.0131)	0.0742 (0.0183)	0.0190 (0.0184)
$OLD\ APART_{60}$			0.310 (0.00926)
$DETER\ SINGLE_{60}$	−1.23 (0.149)		
$DETER\ MULTI_{60}$		−0.941 (0.120)	
$DETER\ APART_{60}$			−1.94 (0.0547)
MLS ZONING	−0.000791 (0.00543)	−0.0000612 (0.000577)	0.000664 (0.000722)
PUBLIC HOUSING (endogenous)		0.0236 (0.179)	1.02 (0.154)
LEASED PUB HOU (endogenous)		−0.954 (0.499)	−3.93 (0.582)
NEW TIGHT (endogenous)	−0.000500 (0.0000909)	−0.000733 (0.000132)	
R^2	.9186	.9540	.9874
SE	.112	.117	.147

activity taking place. The very strong importance of existing stocks is well documented in the table. 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 multifamily 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 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 since apartments already represent a more intensive use of land, and demolition costs are higher, than is the case for singles or multis.

The aggregate data we have suggest that most (three-quarters) of the changes in the singles stock, measured by *CONV SINGLE*, are demolitions (*CONV SINGLE* is negative for every city, town, and district in the sample). Thus, the significantly positive sign on price in the *CONV SINGLE* equation is not surprising. Where returns are rising, existing uses are not abandoned. Similarly, where vacancy rates are high, more demolitions occur. In the other equations, *CONV* 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 it 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 multifamily) units, but that the leased public housing program discourages augmentation of the stock through conversion, or encourages demolitions. However, it should be noted that simply treating these public housing variables as endogenous does not enable us to distinguish between the effects of the public housing programs and the housing conditions that cause a jurisdiction to adopt the public housing approach for solving its housing problems.

SUMMARY

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 structure in the different zones; the demand functions determine the zonal distribution of the population partitioned into three income groups. Through price and vacancy rate change, 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 accommodation prices, vacancy rates, and zonal attributes. This last can be broadly described as including public service and tax rate variables and structural, socio-environmental, 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. Decadal 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 structural types is determined largely by land prices that indicate differing land-capital ratios. Decadal changes in zonal units through conversion-demolition are largely a function of the same expected revenue and cost measures that reflect the number of existing structures of different type, age, and condition in the zone that are available for inexpensive conversion or ripe for demolition.

Our econometric estimations, by TSLS, generally gave encouraging results. The overall fits were reasonable and the signs and patterns of relative magnitude of coefficients across structural 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 in our ongoing work we are attempting to deal with problems exposed in the first stage of our study reported here.

Appendix 3A: List of Variables

Except as indicated, all data pertain to individual zones.

Symbol	*Description*
LOW	Number of family households earning less than $7,000 in 1970 dollars
MIDDLE	Number of family households earning between $7,000 and $15,000 in 1970 dollars
HIGH	Number of family households earning over $15,000 in 1970 dollars
SINGLE	Number of single-family housing units divided by total acreage
MULTI	Number of multifamily housing units divided by total acreage
APART	Number of apartment units divided by total acreage
TOTAL	Total number of housing units

Symbol	Description
NEW SINGLE	Number of single units in 1970 built since 1960
NEW MULTI	Number of multifamily units in 1970 built since 1960
NEW APART	Number of apartment units in 1970 built since 1960
NEW TOTAL	Total number of units in 1970 built since 1960
CONV SINGLE	1960-to-1970 change per acre in stock of single-family units due to conversions, retirements, and demolitions
CONV MULTI	1960-to-1970 change per acre in stock of multifamily units due to conversions, retirements, and demolitions
CONV APART	1960-to-1970 change per acre in stock of apartment units due to conversions, retirements, and demolitions
CONV TOTAL	1960-to-1970 change per acre in total number of housing units not due to new construction
OLD	Percent of 1960 units built before 1930
LARGE	Percent of all units with 7 or more rooms
BATHROOMS	Percentage of all units with more than one bathroom
DETERIORATE	Percentage of all units that are deteriorating
POP DEN	Population per acre of land: residential, vacant, and recreational
BLACK	Percent of population that is nonwhite
CRIME	Comprehensive crime rate of Federal Bureau of Investigation
WELFARE	Percent of households on welfare
VACANT ACRES[a]	Number of acres of vacant land
MLS ZONING	Percent of residential and vacant land zoned for lot sizes larger than 25,000 square feet
SEWER	Sewer availability: percent of population served by public sewers
PT RATIO	Pupils-teacher ratio in high schools
EFF TAX	Effective property tax rate
JOB ACC	General road accessibility to employment defined as $JOB\ ACC^j = \sum_{K=1}^{89} X_K C_{jK}$ where C_{jK} = travel time from zone j to zone K and X_K = employment of income type (*HIGH, MIDDLE,* or *LOW*) in zone K relative to SMSA total employment of that income type
RESIDENTIAL ACRES[a]	Number of acres in residential use
TOTAL ACRES[a]	Total acreage minus acres under open water
HIGHWAY	Highway availability index: [3 (number of limited access super-highways) + 2 (number of four-lane highways) + number of two-lane highways] ÷ total acreage
VAC RATE	Overall housing unit vacancy rate: (units vacant for rent + vacant for sale) ÷ occupied and vacant units
ΔPRICE	Housing price 1970 ÷ housing price 1960
PZ	Fraction of area zoned for minimum lot sizes greater than 25,000 square feet: *MLS ZONING* ÷ 100
UZ	Fraction of area *not* zoned for minimum lot sizes greater than 25,000 square feet: 1 – *PZ*

Symbol	Description
OTHER ACRES[a]	Acres of land devoted to manufacturing
OPEN	Estimate of fraction of area vacant and not subject to minimum lot size zoning: *UZ * VACP*
A	Zero-one dummy: $A = 0$ when town's zoning code prohibits apartments
OLD SINGLE	Estimate of number of single units per acre more than 30 years old: *SINGLE * OLD*
OLD MULTI	Estimate of number of multifamily units per acre in structures more than 30 years old: *MULTI * OLD*
OLD APART	Estimate of number of apartment units per acre in structures more than 30 years old: *APART * OLD*
DETER SINGLE	Estimate of number of single-family units per acre which are deteriorating: *SINGLE * DETERIORATE*
DETER MULTI	Estimate of number of multifamily units per acre which are deteriorating: *MULTI * DETERIORATE*
DETER APART	Estimate of number of apartment units per acre which are deteriorating: *APART * DETERIORATE*
PUBLIC HOUSING	Number of "conventional" and "turnkey" (federal) public housing units per acre in 1974
LEASED PUB HOU	Number of units of federally sponsored leased public housing per acre in 1974
NEW TIGHT	Number of new housing units built during 1960-1970 per acre of vacant land initially available: *NEW TOTAL* ÷ *VACANT ACRES;* measures likelihood of demolition activity as means of making land available for new construction
VACP	*VACANT ACRES* ÷ *TOTAL ACRES*

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

$V1 = 1$ if $VACP < 0.05$; 0 otherwise
$V2 = 1$ if $0.05 \leqslant VACP < 0.10$; 0 otherwise
$V3 = 1$ if $0.10 \leqslant VACP < 0.20$; 0 otherwise
$V4 = 1$ if $0.20 \leqslant VACP < 0.30$; 0 otherwise
$V5 = 1$ if $0.30 \leqslant VACP < 0.40$; 0 otherwise
$V6 = 1$ if $0.40 \leqslant VACP < 0.50$; 0 otherwise
$V7 = 1$ if $0.50 \leqslant VACP$; 0 otherwise

[a]The 1960 acreage data is derived from a 1963 land-use survey; the 1970 data, from a 1972 survey.

NOTES TO CHAPTER THREE

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

2. 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.

3. Our more recent econometric work improves on the treatment of price by substituting two different price variables for the simple one used here. One measures a given zone's price relative to the average for zones closely substitutable to it; the other measures the average for the zone and that closely substitutable group relative to the SMSA average.

4. Indexes could not be constructed for some zones. Therefore, the rates of change over the decade 1960-1970 were projected upon the census rates of change of value and composition to obtain an approximation for the other zones.

5. The dependent variables of these estimated equations contain households of all races. Currently we are separating out the nonwhite households so as to estimate separate income class demand equations for them, and determine whether low-income whites have similar preferences to whites in the high- and middle-income groups or are closer to the present mixed low-income group.

6. In a more recent treatment than is reported here we attempt to elaborate relative conversion costs further by separately determining conversions to the different structural types, and by using as explanatory variables in the separate equations the number of existing units of each structural type.

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Comments on Chapter Three

John M. Quigley

Few economists would quarrel with an econometric analysis of housing market behavior designed to pay careful attention to the three characteristics of the market for residential services—durability, fixity, and heterogeneity—that distinguish it from most other economic markets.

In reacting to this "preliminary analysis" or progress report on model building, I wish to emphasize two points in particular. First, to my knowledge, this analysis represents the first attempt to sketch out and estimate empirically a model of housing supply behavior which differentiates housing by type over urban space. Secondly, the class of models represented by this work-in-progress is directed toward a quite demanding standard. Until quite recently, there were practically no analyses of the housing market that were not based on the convenient, but rather unsatisfactory, assumptions that housing services are homogeneous, that vacancy rates are zero, that markets are in long-run equilibrium, and that locations are along a line. A research design intended to deal in a serious way with the complexity of the durable, heterogeneous, and locationally fixed housing commodity has a potentially high payoff.

A serious investigation of the supply and demand for housing services within a single metropolitan area faces formidable difficulties. What we call the housing market is really an interrelated market for two kinds of goods. One of these is a market for the services of residential capital—those services provided by a structure type, a

Note: In preparing these remarks, I benefited from discussion with Eric A. Hanushek.

configuration of living space, and so forth. However, since the consumption of these services is site specific, the economic actors must also compete in a market for locations—which provide such services as accessibility, public goods, and "neighborhoods."

This complementarity suggests several possible strategies in developing econometric models of these markets for subsequent testing. Strategy A, the most desirable but the most complex approach, would involve specifying the complete set of interrelated supply and demand relationships, to include both housing attributes and location simultaneously. The objective of this strategy would be to untangle the choices really being made by economic actors:

1. Households, which substitute among alternative housing units or "types" and among alternative locations or "zones" in response to relative prices, that is, the market price of each type of housing available in each zone.
2. Entrepreneurs, who produce, through new construction or through conversion, changes in the number of units of various types at alternative locations in response to these same market prices.

The key point is that market prices, which vary jointly by type and location, make some types of residential capital more desirable to certain kinds of households at one location and to other kinds of households at other locations. This same set of prices causes the profitability of supply transformations to vary by type and location. An equilibrating process adjusts prices and vacancy rates to reduce suppliers' profit differentials and households' incentives to move. Something tolerably approaching a short-run equilibrium may well result.

The mere outline of the intricacy implicit in this line of inquiry for modeling housing market interactions may help us understand why little progress has been made in implementing such a complex strategy. Since there are many possibilities for substitution in consumption and in production, there are a host of potentially important cross-price effects that affect the behavior of consumers and suppliers. In addition, there are unresolved measurement problems inhibiting econometric applications; we have only a crude understanding of the appropriate way to measure those housing bundles whose prices vary and those significant characteristics of locations over which they vary.

Two more limited research strategies would focus serious attention on either housing services or locational attributes and would treat the other half of this market somewhat superficially.

For example, abstratcing from locational considerations, strategy B would specify a behavioral model for exploring the supply and demand relationships for housing bundles or types of dwellings. Such a strategy would explore the interrelationships among the segmented submarkets for types of dwellings that are only imperfectly linked through substitutions in production and consumption. In its pure form, this strategy would assume that locational attributes were ubiquitous or would "hold them constant" in a crude way to focus attention on the market for housing services. Alternatively, strategy C would focus attention on the supplies of and the demands for locational characteristics by different kinds of households and would neglect or "hold constant" in some plausible way the stocks of residential capital and their spatial distribution. Either of these lines of inquiry would lead to an econometric model which would provide only limited, but potentially useful, insight into the complex interdependencies of the urban housing market; either would improve our understanding of how the market process works.

Bradbury et al. claim to "model a demand for housing accommodation and its supply" and present "preliminary estimates as evidence of its promise." Since the study is largely empirically oriented, its success must be judged, not by the revelation of theoretical insight, but on other important grounds—the choice of research strategy, the attention to issues of measurement, and the interest and importance of the empirical results.

The authors choose a curious mixed strategy for analyzing behavior in the housing market. They discuss their strategy as if they had estimated supply and demand relationships using strategy A, but in fact they have chosen the strategy "one from column B and one from column C."

The analysis presents little justification for the formulation of the particular supply and demand relationships the authors choose to estimate. They rely mainly on Marshallian insight that a standard supply and demand curve characterize a market. Indeed, we do not discover until later that the analysis has been formulated so that there is no prior sign on the slope of the supply curve and that the demand curve could have a positive slope for high-income households!

The verbal analysis includes an excellent discussion of the role of prices and vacancy rates in equilibrating the supply and demand sides of the market, but it appears that in empirical application the supplies and demands are for different goods in separate but related markets.

The demand side of the market is characterized by several equations that focus on locational attributes and virtually ignore housing availability; the strategy comes from column C. Regressions are reported that relate changes in population distributions across eighty-nine locations or zones to nine variables measuring the locational attributes of the zones, three measures of the housing stock, a price change term, and the vacancy rate.

This formulation implicitly assumes that housing attributes are homogeneous within zones (which are defined as seventy-five suburban towns and fourteen zones in the city of Boston) and that they are virtually ubiquitous across the metropolitan area. The formulation assumes away virtually any spatial differentiation among housing stocks that would cause households to substitute among different locations, i.e., it disregards characteristics of the housing stock that are available in suburban Lincoln but not the South End of Boston and which would affect consumer choice.

Of particular importance in the analysis is the price measure because it is the key variable in motivating housing demanders to substitute among housing types and locations. The price change term is computed from an index based on repeat sales in each of the eighty-nine zones. The only thing that matters in the derivation of this index is the sale price of a given property in two calendar years. Thus the measure implicitly assumes that the prices of all dwelling units in each town changed proportionately throughout the decade. To the extent that there is more turnover in single-family housing than in multifamily or apartment units, the price term does not measure price variations in the latter two very well. In any case, the construction of the index assumes that the rate of price change of all properties within each of the towns is identical. But if the rates of price appreciation of different types of residential housing varied for the metropolitan area as a whole, the index could well be measuring the distribution of the types of housing across towns. (Indeed, if the rates of price appreciation were *constant* for each housing type in the metropolitan area, but varied among housing types, the price index would *only* be related to the distribution of housing across towns, or at least, the distribution of repeat sales.)

In summary, the estimated demand equation relates changes in proportions of income classes in each zone to a somewhat ad hoc set of measures of changes in zonal characteristics and price, and practically ignores changes in housing characteristics.[1]

The strategy behind the supply analysis, in contrast, comes from column B. The authors present several equations relating changes in housing accommodations in each zone to vacancy rates, their changes, the preexisting stock, and available vacant land, but otherwise the locational and demographic characteristics of the towns, which are so important in the demand analysis, are virtually ignored. The same ambiguous price variable is used to investigate the supply response, and it is noted that "the price variable has a critical importance in leading the market's adjustment process out of disequilibrium."[2]

Note that the demand analysis measures the demand for location, with little effort to "hold constant" the spatial distribution of residential capital, with no effort to "hold constant" the locational differences among zones. Is the price term to be interpreted as a capitalized location rent (in the demand equation) or is it interpreted as the output price of housing (in the supply equation)? If so, what is the slope of the supply curve? What is the anticipated behavior of demanders for owner-occupied units, who are 54 percent of the Boston housing market?

This is, of course, an empirical question, and the proof of an econometric analysis is in the estimates. There are rigorous statistical standards, and there are looser interpretations of patterns or coefficients—their signs, magnitudes, and significance levels. I would submit, however, that it takes unusually strong and sometimes puzzling a priori notions to analyze the results displayed in this study and conclude that the "results display encouraging consistency with theoretical expectation for both demand and supply." When the authors examine the price variable in the demand equations, they conclude it is "one of the economically most significant variables." When others look at the price coefficients they may see t ratios of 1.40, 0.76, and 0.33.

In the supply equations, the effect of higher prices is to stimulate conversions of existing dwelling units from higher density to lower density structure types. Higher prices do stimulate new-construction activity in the aggregate, but are not considered to influence its distribution among structure types.

Since the price term used throughout the supply and demand analysis is called upon to perform two functions—to measure the price of sites when housing is not distinguished and the price of housing when sites are not distinguished—it is possible that it measures neither very adequately. The results of the empirical analysis also "display encouraging consistency with [this] theoretical expectation."

NOTES TO COMMENTS ON CHAPTER THREE

1. It is difficult to understand the reasoning which leads to the regression model with an endogenous price change and an exogenous tax change. Why are

1960 values used for the vacancy rate, the proportion of "old" houses, and the proportion black, and 1960-1970 relative changes used for the other variables reported in Table 3-1. What is even more curious is that the latter two variables are measured as 1960 levels in this version of the studv and were measured as 1960-1970 relative changes in the original version.

2. Why was the price term included in the regression for estimating the distribution of new units across towns and excluded from the regressions for estimating the distribution of new single-family and apartment units?

It is even more difficult to understand why the analysts chose such a peculiar functional form for estimating the latter regression, in effect including a vector of zeros as observations on all variables in towns where apartments are banned.

Finally, there is no obvious reason why the dependent variables in the new-construction regressions should be measured as ratios to the number of existing dwelling units in 1960 while the dependent variables in the conversion regressions should be measured as ratios to the land area of the town.