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Author
Rothenberg, Jerome

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NEW CONSTRUCTION VS. REHABILITATION:
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AMERICA'S HOUSING NEEDS

BY

JEROME ROTENBERG

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New Construction vs. Rehabilitation: The Tradeoff in Meeting America's Housing Needs*

Jerome Rothenberg
Professor of Economics
Department of Economics
M.I.T.

I. Introduction

A. Non-Uniformities in Housing

Much of the academic thinking about urban housing of the last 30 years has been macroeconomic in character. The unit of analysis has been the "total amount of housing". Research sought the determinants of the total amount of housing; academic public policy discussions were couched in terms of targeted changes in that total. Some differentiation was introduced into the analysis to accommodate spatial location. But basic homogeneity of housing was assumed. With this approach it was natural to treat supply only in terms of new construction, and durability - if at all - only as the temporal process of inevitable aging: an exogenous steady, irreversible depreciation.

Such an approach misses much of what is distinctive about urban housing with respect to both description and actual public policy concerns. Urban housing is highly heterogeneous - in structure, condition, land, neighborhood characteristics and public services, as well as location. These differences matter. The housing market rarely moves uniformly across these differences.
Since different kinds of households inhabit the different parts of the housing spectrum, the distribution of real income depends on the character of the non-uniform changes that occur in the market. Moreover, since most public policy goals are actually couched in terms of specific household types or housing types, but not housing generally, non-uniformity has important implications for a non-uniform distribution of benefits and thus, for the extent to which real policy goals are met.

To bring these differences into focus requires a microeconomic approach, one in which the unit of analysis makes it possible to deal explicitly with intrinsic housing heterogeneity, and which provides a structure for understanding the non-uniform transmission of impulses through the overall market.

With such a framework market supply can be treated as having more than one generalized kind of process – new construction. The distinction between new and existing housing units can be usefully considered, as well as the fact that existing units can be modified in a variety of ways by their owners, making this a counterpart supply process. These modifications represent supply accommodations to meet housing wants just as does new construction, and they represent thereby a substitute to new construction in some respects. Having their origin in a highly heterogeneous housing stock subject to non-uniform conditions at any one time, they too are likely to occur in non-uniform ways. To understand them requires understanding the way the market for a strongly differentiated commodity operates.

One significant class of modifications is rehabilitation, the upgrading of existing units. Non-uniformities in housing, and especially the highly
non-uniform incidence of new construction, have led many to argue that the public policy goal of better housing for poorer households may be only very inefficiently served through new construction, and that emphasis on rehabilitation would be more effective. The present paper addresses this question.

Having couched the question of new construction vs. rehabilitation for meeting policy goals in the context of housing market non-uniformities, it fails to take advantage of the strengths of that focus to restrict attention to only the so-called rehabilitation class of modifications. Non-upgrading and even downgrading changes in some housing units can serve to upgrade the housing standards of poorer households. To understand how the housing welfare of any particular household groups is abetted or hurt by supply and demand forces in the housing market requires understanding a highly complex network of linked occupancy changes, modifications and new construction over a much wider range of the diversified households and units of the housing stock. This paper attempts to apply just such an analysis to illuminate policy issues involving new construction and modifications of existing units. We begin by comparing these two supply modes.

B. New Construction, Modification of Existing Units, and the Analysis of the Housing Market

The extreme market-relevant durability of housing means that new construction provides only a tiny part (about 1-3%) of the occupied housing units each year. The overwhelming portion of each year’s occupancies are provided by units built in earlier years, with substantial percentages deriving from units decades old. This does not, however, mean that the supply of housing is essentially frozen by past decisions. First, use and
aging affect the quality of services generated by existing houses. Second, houses built in the past can be modified by their owners in a variety of ways in each period: size, architectural features, tenure status, the number (and size) of separate units within each house, the condition of the premises (maintenance level, state of repairs).

These modifications are not accidental, nor are they passive, "automatic" adjustments to the use and aging of structures. Rather, they are considered owner responses to changes in desired housing consumption by the owner and/or more favorable marketability (whether or not the owner intends to sell the property in the present period), considering current market conditions. In both respects they are supplier responses to some aspects of market change. As such, they are behaviorally comparable to new construction as a supply response to ongoing market conditions. Because such modifications can potentially affect all of the existing housing stock, their importance in affecting the characteristics of the overall supply of housing is potentially at least as important as new construction. In particular circumstances their influence on overall supply characteristics may considerably exceed that of new construction in terms of sheer numbers of units involved.

The influence of stock modification may be especially important, moreover, in terms other than of sheer numbers. New construction and modification have significantly uneven incidence over different kinds of housing services. In the U.S. new construction is much more important in providing high quality housing services than low; modifications are more
important in the latter than in the former. Indeed, most low quality units are not provided directly by new construction but only indirectly by units originally built to provide higher quality services and subsequently modified to furnish services of lower qualities. Improvements in housing consumption by those consuming low levels of housing generally are achieved directly or indirectly (through linked chains of occupancy changes) via modifications in existing units.

This has important policy implications. The attempt to improve the housing welfare of poor and modest income households may depend crucially on modifications in the existing stock rather than on new construction, both because thereby more units can be affected, and because whatever improvements occur may be brought about at lower - and thus affordable - cost.

Whatever the salience of stock modifications, however, it cannot be examined or manipulated without understanding new construction as well, because new construction and stock modification are substitute forms of supply response, and so are mutually interactive. Indeed, only such a joint examination can reveal whether modification is more or less relevant in fact for specific policy purposes than new construction; and in what ways. In the present paper, therefore, I am treating the relationship between new construction and stock modification as the core of the analysis. Despite the title, I treat not simply the rehabilitation, or upgrading, aspect of stock modification, but also owners' acquiescence in, or actual acceleration of, downgrading of units. My reason for the larger scope is threefold: 1) a given existing unit may be alternatively upgraded or downgraded, depending on differential market advantages; 2) a given target service level can be
competitively aimed at by both units upgraded to such a level and by
different units downgraded to that level; 3) upgrading and downgrading may
have different competitive relationships with new construction.

My informal discussion so far strongly suggests that discussion of stock
modification relates to changes in quality of housing services. An analytic
treatment of such changes must therefore have room for a quality dimension in
housing. The model in which I embed the analysis of stock modification and
new construction makes quality differences the core.¹ Its central tenet is a
multi-dimensional heterogeneity of urban housing. Housing units differ in
terms of structural attributes, size, condition, tenure status, as well as
lot characteristics, neighborhood characteristics and location. They
represent therefore sets of commodities with varying degrees of
substitutability among one another: some are close enough substitutes to be
effectively the same commodity, others are so little substitutive as to be
virtually different commodities. For a single urban area, therefore, the
housing market is not really a single market for one commodity but a complex
of submarkets, within each of which the units are very close substitutes, but
among which there are varying degrees of substitutability.

The quality of housing services is established by a combination of
demand and supply forces in the market, demarcating an ordering of clusters
which the market treats as aggregatively a hierarchy of groups. Housing
units in the same group effectively have the same quality level, units in
groups lower in the hierarchy have lower quality in the same degree as the
hierarchical ordering of the groups. It is these quality levels that
delineate submarkets. Within each submarket housing units have the same
quality level but different combinations of housing attributes. The
different attribute combinations are treated by the market as equivalent
marginally as tradeoffs in exchange. They reflect equal marginal rates of
substitution both for demanders and suppliers of housing services. In any
short - and - middle run period, demand and/or supply changes can change both
relative prices and exchange (occupancy) quantities. Because both demand and
supply adjustments to market changes can involve long lags, price and
quantity changes representing incomplete adjustments can persist for
considerable periods. In the long-run all adjustments are assumed complete,
but some demand and supply changes lead to "permanent" shifts in inter-
submarket relations. Some of these permanent shifts involve the relation
between new construction and stock modification.

Given this thumbnail sketch of the broader analytic context of the
present examination, I now turn to the relevant specifics of the model.

The paper is organized as follows, Section II presents the concepts of
demand and supply in the complex of housing submarkets and individual
optimizing demand and supply behavior. While the model deals with short and
intermediate run phenomena as well as long-run--indeed, the former two have
most interesting dynamic and quasi-dynamic properties - for the present
purposes I am concentrating on long-run phenomena in order to highlight the
relatively "permanent" relationships between new construction and stock
modification, avoiding market patterns that may be only "temporary".

Section III gives the conditions for long-run general equilibrium in the
complex of housing submarkets. Section IV examines various relationships
among different stock modifications and new construction. Section VI briefly concludes with some policy implications of these relationships.

II. A Model of Segmented Housing Submarkets

The relationship between new construction and stock modification, the focus of this paper, is illuminated in the elaborate model of the urban housing market that my colleagues and I have been developing for a number of years; but it is not the chief focus of that model. In presenting the model I shall therefore skim over, or omit entirely, elements that are not central to the present theme. The exposition of the model will therefore be uneven, some parts described more informally than others.

We assume housing services are supplied by housing units. Housing structures contain one or more housing units; a given structure can be modified to contain fewer or more units by changing the size of the units or of the structure. A housing unit can be characterized as a vector of its quality level, combination of housing attributes, and age. Its attributes include numerous structural features like size, number and character of rooms, heating, architectural style, materials and condition; lot features like size, placement, topography; neighborhood characteristics like socio-economic mix, shopping, public services, physical amenities and disamenities; accessibility to desirable destinations.

Houses, and their component units, are highly durable, but: 1) they age, in that with advancing age it is increasingly expensive to maintain and repair the premises so that it may continue to render the same quality level of services; 2) both houses, and their units, can be modified in various
ways: size, rooms, architecture, and other structural features; number of constituent units per house; condition; and tenure status. Units can be modified either to increase or to decrease their quality level. Improvements come about by physical investments akin to new construction, or by raising condition through maintenance and repair outlays in excess of what is necessary simply to maintain services at the same level. Downgrading is accomplished either by lowering condition through undermaintaining over a period of time, or by splitting existing units in a house into more but smaller units. The former method decreases the quality (and so the market value) of the house as a whole, the latter decreases the quality of the constituent units but raises the market value of the house as a whole. In what follows I shall refer to all forms of modification as "conversions", using this term more broadly than the narrower conventional reference to tenure or residential - non-residential use alone.

Users of housing services - demanders - are households, assumed to possess a variety of income levels, socio-economic characteristics and idiosyncratic preferences concerning housing consumption: quality level of housing vs. non-housing consumption and the internal mix of housing attributes. Both aspects of preferences are assumed to permit smooth tradeoffs among the components of choice.

Suppliers of housing services are owners of existing housing units (housing structures) and builders of new units. Existing owners possess a highly heterogeneous stock of units. Builders are more homogeneous in knowledge of new building prospects and in access to building materials and credit. In some applications of the model, for example, where short-and
intermediate-run phenomena are considered, it is important to specify the exact degree of homogeneity - especially with regard to habitual specialization by builders in specific types of housing (e.g. by quality level). It is less pertinent here. Builders are assumed to be largely, but not necessarily perfectly, similar with regard to entry, mobility of resources, cost functions, etc.

A Individual Demand

Equilibrium long-run demand for any given household is arrived at as follows. The consumer has to choose from among available housing units - a set of discrete packages comprising quality, the vector of housing attributes and age: \((H, R, A)\). Each package has a single price (market value, \(N^1\), for ownership units, rental level, \(r\), for rental units) associated with it. Constrained by its income (permanent income, wealth) and these prices, the household has essentially a three-part choice: 1) optimal \(H\) relative to non-housing consumption (with numeraire price \(= 1\)), \(Z\); 2) optimal mix of attributes to produce whatever quality level is desired; 3) optimal age for quality and mix: thus, \((H, R, A)\). Given a wide variety of \(H, R,\) and \(A\) in the stock of available units and a high degree of buyer and seller competition among them, relative market values (rentals) for units in this stock imply both a set of prices for individual attributes \((p)\), for individual quality levels \((P)\), and for age \((P_A)\). Quality and attribute mix are experienced directly by the household and so appear in its utility function, but age is experienced only indirectly in the size of maintenance and repair needed, so does not appear in the utility function.
Utility maximization, which consists in choosing the best package with respect to all three aspects, can be formally looked at as solving the following set of conditions:

\[ \frac{U_H}{U_Z|H_x} = \frac{dP}{dH} |H_x \]

(2) \[ \frac{u_{hi}}{u_{hj}} = \frac{p_i}{p_j} \quad \text{all } i,j \text{ in } (R) \]

(3) \[ \frac{\partial C}{\partial A} = - \frac{\partial MV}{\partial A} \]

where C is the present discounted lifetime cost of owning (using) a housing unit (assuming an infinite lifetime), U is the household's utility function \( U = u[Z,(H,R)] \)

Eq. (1) indicates that optimal quality level is that for which the marginal rate of substitution between housing quality and non-housing consumption equals the ratio of prices for extra quality and extra Z.

Eq. (2) indicates that whatever the level of quality chosen, (like the condition for a least cost combination of inputs for every given level of output in production theory), each pair of housing attributes \( h_i \) and \( h_j \) should be combined in quantities such that their relative contribution to housing consumption (the marginal rate of substitution between \( i \) and \( j \)) equals the implicit attribute price ratio between them.

Eq. (3) indicates that age should be chosen such that the degree to which higher age increases present discounted value of ownership costs of a unit exactly equals its discount in market values.

Equations (1) and (2) refer to personal features of the given households' consumption (the utility function), but equation (3) does not.
It is assumed that all owners (users) experience the same marginal cost of age, so competition in the market will establish a set of market value discounts such that all should be indifferent to age. Therefore, in market equilibrium all ages are equally attractive: there is no one best or small subset of best ages for the household.

For every set of market values on housing packages - implying particular quality level and attribute prices - the household will select the package with optimal quality and attribute mix. Systematic variations in quality or attribute prices will trace out quality-demand or attribute-demand functions and, in any case, successive optimal packages. Each household facing the same price sets will make an optimal choice reflecting its own utility function and budget constraint. Thus, for a given overall population of heterogeneous households any set of market values on available housing units will generate an aggregate demand for the various kinds of housing available.

The model focuses heavily on the quality level dimension of housing heterogeneity, so we are especially concerned with the number of units of each quality level demanded. Each quality level represents units which are only imperfect substitutes for units at other quality levels. The greater the difference in quality between any two units the weaker generally is the degree of substitutability between them. Indeed, since quality level can be scaled through abstraction from actual market exchanges, the relative placement of units on the quality scale provides a good empirical approximation to a complete ordering of the degree of substitutability among every pair. It is this property that accounts for our central interest in
the quality dimension, because it thereby furnishes a powerful theoretical tool for organizing the analysis of the interaction of a large set of submarkets related by commodities with differing degrees of substitutability.

We therefore conceive of the urban housing market complex as a set of submarkets defined by quality level (or, more empirically, defined by small intervals in the quality level spectrum). Both aggregate demand and supply are translated into number of units either demanded or supplied in each of the quality submarkets. The aggregate demand function noted above stipulates the number of units demanded in each quality submarket. For each submarket the units demanded will have the same quality level (thin band) but generally will differ in attribute mix and age. So each submarket is homogeneous in one dimension but heterogeneous in others. This disparity influences the working of the system of submarket interactions.

B. Individual Supply

There are two types of suppliers of housing services: owners of existing housing units (whether landlords, owner-occupanciers, or prospective sellers of existing houses) and builders of new units. Each type has its distinctive cost function for supplying services, but all are assumed to have equal access to demanders in all the quality submarkets - and essentially equal information about such opportunities. New builders can build at any quality they wish, and any attribute mix, except that they are constrained to build only on hitherto undeveloped land unless they are willing to demolish and clear existing structures from already-developed land, which is expensive. Owners of existing units may continue to provide services from these units similar to what they have been providing so long as they maintain
and repair the units appropriately. Alternatively, they may convert their property in a variety of ways, transforming both quality level and attribute mix. Each form of conversion has its own production and cost functions, but all are constrained by the particular initial configuration of capital represented by the existing unit - its quality level, attribute mix and age.

1. **New Construction Supply**

Each potential new builder can produce at least one unit to any quality level/attribute mix desired. In so doing it (they) can be sold (rented) for the market value (rental) prevailing on the market for like units, whether existing or new units being sold by other builders, (each supplier is competitively small, so its output has no effect on prices). All builders have access to the same technology, and we assume they will all choose the same production and cost functions. Their optimum choice of investment has three aspects: 1) the least cost attribute mix for any given quality level desired, 2) the most profitable quality level, 3) the optimal number of units to build at that level/mix, whether zero or some positive number. These choices are assumed to be made to maximize the rate of return on the builder’s net assets, i.e.:

\[
\text{(4) } \max \rho = \frac{(MV-C)}{C} \alpha + \bar{\rho}(1-\alpha) \text{ subject to } f(nC) = \alpha T
\]

where \(\rho\) is the rate of return on the builder’s portfolio

- \(n\) is the number of units of the optimal housing investment
- \(MV\) is the market value (present discounted value of expected future revenue streams) from optimal type of unit built, per unit
- \(C\) is the cost of the optimal type of unit built, per unit
\( \alpha \) is the portion of the builder's net assets taken by new housing construction.

\( f(\cdot) \) is the builder's equity required by a housing cost of \( nC \).

\( \bar{p} \) is the net rate of return on total non-housing investment (including borrowing as negative investment).

\( T \) is the total of the builder's net assets.

At each given time the builder faces a schedule of market value obtainable for units - new or existing - at each quality level: \( MV(H) \). The cost of a new unit at any quality is composed of two elements:

\[
(5) \quad C(H) = C_K(H) + C_U(H, \lambda = 0)
\]

where \( C \) is total cost of a newly built unit at quality level \( H \).

\( C_K \) is the construction cost (embodied capital) of a new unit at \( H \).

\( C_U \) is the present discount value of the maintenance and repair cost of a unit at \( H \) with zero years of aging (\( \lambda = 0 \)).

Since our model does not include scale effects of construction, costs and revenues are linear for multiples of new units produced. Therefore portfolio rate of return maximization will correspond to housing rate of return maximization: any resources invested in housing should seek that investment for which rate of return on those resources is maximized.

Multiples of any quantum of investment in a particular kind of housing will earn the same rate of return as that quantum. So, if any investment is to be carried out in housing, it should be for that type of unit for which rate of return on the unit investment is maximized, or where:

\[
(6) \quad \frac{\delta \log MV}{\delta H} = \frac{\delta \log C}{\delta H}
\]
The attribute mix that either minimizes the total cost of reaching any $H$, or alternatively, that maximize the market value of any input bundle used, is that for which (analogously with housing demand):

$$ \frac{\partial C}{\partial h_i} + \frac{\partial C}{\partial h_j} = \frac{P_i}{P_j} $$

Conditions (6) & (7) determine the highest rate of return obtainable from new construction in housing. Let this be $\rho^H$. The builder should build at least one such new unit or not as:

$$ \rho^H \geq \rho $$

If $\rho^H > \rho$, build; if $\rho^H < \rho$, do not build; if $\rho^H = \rho$, housing investment is indifferent with non-housing investment. Amount of total successful housing investment is assumed limited by credit constraints.

For each $\text{MV}(H)$, $(p)$, $C(H)$ set, the builder will make a particular optimal number and kind of building decision. Changes in those parameters will change the choice. I shall characterize these choices below.

2. **Conversion Supply**

Owners of existing housing units have a number of options will respect to their property: 1) maintain at the same quality level, 2) upgrade, 3) downgrade in finite degree, 4) abandon the property to non-use, ending its provision of housing services, 5) convert the property outright to a non-housing use. Conditions for the last two default options are simply that, for the fifth, the opportunity cost of using the capital embodied in the structure and any further operational (maintenance and repair) resources for housing services, is greater than the highest return obtainable from
any continued housing use. For the fourth, the rate of return from using the structure plus any necessary complementary operational resources, is less for any use whatever than the opportunity rate of return of the necessary operational resources alone.

For all of the continued housing options owners face potential returns indicated in the same market valuation function, $MV(H, R, A)$, that confronts builders and housing demanders. Their costs of achieving such returns, however, differ from those of new builders. Each type of conversion including sustaining the same level, has its distinctive production and cost functions. These differences lie behind the choice by each owner of an optimal conversion action.

Sustaining the same quality level for a unit requires using operational resources for its maintenance/repair to the degree necessary to offset usage and passage of time. It depends in reality on the particularities of the attribute mix (materials, architecture, etc.) as well as on $H$ and $A$, but in this model we assume that much of what is needed can be explained by $H$ and $A$. Upward conversion of a unit has three main routes: 1) physical additions, like new construction, 2) overmaintenance to enhance its condition, 3) consolidating of more numerous, smaller units in a structure into fewer but larger units. These three clearly have different production functions and so different cost schedules, and are differentially affected by exogenous changes. Yet combinations of them are often used together in complementary packages.

Downward conversion of a unit has two dominant forms: 1) undermaintenance to lower the condition of the unit. 2) splitting of fewer.
larger units in a structure into more numerous, smaller units. These differ notably from one another and from the routes to upward conversion. Splitting involves investing resources deliberately to lower the quality of housing units, thereby deliberately lowering their market value. The action would be difficult to rationalize except that it results in a larger number of units in the affected structure and, if appropriately done as a response to changing market conditions, it has the effect of raising the overall market value of the structure as a whole. This makes clear that the individual housing unit is not always the appropriate decision unit for a housing investment. For some owners it is a whole house, or even clusters of houses that form the real unit of decision making.

Undermaintenance is really disinvestment in housing capital. Maintenance is a complementary input with capital to provide housing services and keep its future productivity intact. Undermaintenance allows aging and use to depreciate housing capital. It permits a lowering of housing quality in exchange for a saving on current outlays. The gain is the opportunity use of resources elsewhere than in helping the given unit to provide housing, the loss is the deliberate decline experienced in the market value of the unit. An additional special element is involved in this form of conversion - namely, that undermaintenance is a considerably slower means of achieving significant quality decline than splitting: actual decline cumulates under the gradual pressure of use and aging not offset by maintenance and repair. It is like the negative of the process of creating wine - a considerable passage of time is needed for "destructive aging."
A change in tenure affects the rate of return by taking advantage of the lack of perfect substitutability between ownership and rental units otherwise highly similar. For a pure tenure change no costs may be incurred. Usually, however, physical modification accompanies tenure change, because the imperfect substitutability across tenures is at least partly due to the degree of idiosyncratic special tailoring of units to meet special consumption tastes. Rental units are usually more staple, interchangeable across tastes, owner-occupier units more specialized. A tenure shift is thus likely to be accompanied by physical modification to make the unit more appropriate to its new status.

The above discussion of conversion suggests that the appropriate concept of cost for conversions is complex. It is summarized in (9) for some unit $\alpha$:

\begin{equation}
\alpha C_{ijk} = C_K(H_i, R^\alpha) + C_M^{ij}[M_k(R^\alpha, A^\alpha)] + C_U(H_j, R^\alpha, A^\alpha) + C_T[M_k(H_i - H_j)]
\end{equation}

where $\alpha C_{ijk}$ is the total cost of a unit $\alpha$ converted from quality submarket $i$ to submarket $j$ by conversion method $k$.

$C_K(\cdot)$ is the opportunity cost of the capital embodied by the unit (approximated by original construction cost), or remaining original cost not amortized, whichever is larger.

$C_M^{ij}[M_k(\cdot)]$ is the cost of actually modifying the unit from level $i$ to level $j$, by method $k$.

$C_U(\cdot)$ is the cost of maintaining the unit at the destination level $j$.

$C_T(\cdot)$ is the opportunity cost of the time taken to convert the unit.
from $i$ to $j$ in terms of optimal use of the property.

So the cost of making the shift from $i$ to $j$, the marginal conversion cost is:

$$(9a) \Delta C_{ij} = \alpha C_{ij} - \alpha C(H_i)$$

$$= c_{ij} + c_u(H_j) - c_u(H_i)$$

$$+ c_T[M_k(H_i - H_j)]$$

So conversion costs are partly direct outlays, partly opportunities foregone, and they depend on the distance between origins and destinations, on age of unit, on specific attribute characteristics, and on mode of conversion.

The owner of each housing unit chooses among all these conversion options - including the no-change option, which we have seen requires a specific kind of action as much as any other - on the basis of their respective expected rates of returns, a return not only to any additional resources expended, but to the opportunity cost embedded in the continued use in housing of the unit itself. Abandonment and conversion to non-housing use compete with the various housing retention alternatives. That alternative with highest rate of return is chosen; it specifies the quality level and tenure status destination, and the conversion method to be used for each unit. It also indicates any change in the number of units per house.

All owners of existing units face the same expected proceeds ($\Delta V$ function), but they differ significantly with respect to costs. Costs depend not only on destination but on origin, age, attribute characteristics and conversion method - especially whether an upward or downward conversion is
involved. So any two units starting in the same quality submarket may, though facing the same market value opportunities, because of attribute or age differences select different conversions and end up in different submarkets. A fortiori, units beginning in different submarkets are quite likely to adopt different conversion choices. This means especially that conversions are not likely to concentrate very heavily in one or a few destinations. This contrasts with new construction. Since in our model builders face similar revenue and cost prospects, many sets of housing prices can lead to overwhelming concentration of new construction in very few submarkets. These relationships will be elaborated — along with others — in later sections.

This section indicates that the population of owners of the existing housing stock will, when facing any particular set of housing and input prices, and an opportunity cost of capital for use in housing, adopt a set of various conversion response, leading to a new distribution of units among quality submarkets. Some submarkets will gain on balance, some will lose, and some remain unchanged. Like new construction supply, an aggregate conversion supply function will indicate, for each set of prices, the number of units added to, or subtracted from, each quality submarket.

III. General Equilibrium of the Housing Market Complex

A. Submarket Aggregate Demand and Supply

At period $t_0$ assume we have a complete set of market values for all housing units and houses, implying a set of housing attribute prices $p ( = \{p_0, p_20, \ldots\})$ and quality submarket prices $P ( = \{P_1, P_2, \ldots, P_m\})$. Given a particular population with specified demographic, socio-economic features,
these prices enable us to predict, via our demand analysis, a total number of units demanded in each quality submarket \(i\), and the set of attribute mixes at each such \(i\). If we hypothetically vary each \(P_i\), holding other quality prices, and all attribute prices constant, we can predict a schedule of demands for each quality level \(i\). To approximate a long-run situation we assume that offsetting general population changes occur (such as new household entrants to offset household terminations) so as to keep aggregate demographic and socio-economic characteristics unchanged over the period.

Our analysis generates an aggregate long-run quality level demand function for all quality levels: equation (10):

\[
D_{Q_i} = D(P_i, \{P_j | j \neq i\}, p) \quad \text{all } i \quad \text{where } P_i, P_j \text{ are implicit prices of quality levels } H_i, H_j
\]

\(P\) is the set of implicit prices of attributes \((h)\)^+. Hypothetically varying each attribute price similarly generates an aggregate long-run attribute demand function. Combining quality and attribute demand functions gives hypothetical aggregate long-run demands for specific quality-mix configurations. In what follows we shall be primarily interested in quality level equilibrium; so we implicitly assume that the set of attribute prices remains essentially unaffected by inter-quality level adjustments.

On the supply side, for any complete set of market values for available units at time \(t_0\) implying sets \((p_0, P_0)\) and initial stocks of housing \((H)_0\), our new and conversion supply functions determine the number and character of new units built and the character of the change, if any, for each group of existing units. The effect of all these supply actions on any one quality
level-attribute mix group is their algebraic composite. Since we are here too interested primarily in quality submarket equilibrium, we focus on aggregate supply to each quality submarket, assuming mix unaffected by this equilibration process. For any quality submarket \( i \) the total number of units ending up at that submarket after all supply adjustment plans have had an opportunity to come to function in the market is the algebraic sum of the following: 1) the number of new units constructed at submarket \( i \) \( S^t_{B_i} \); 2) plus the total number of units originating at \( i \) at the end of period \( t_o \), \( S^Q_{E_i} \); 3) plus the number units originating at each submarket \( j \) (all \( j=1, 2, \ldots, i-1, i+1, \ldots n \)) and converted to \( i \) between \( t_o \) and \( t_1 \), \( S^Q_{E_i} = \sum_{j \neq i} S^Q_{j} \); 4) minus the number originating at \( i \) and converted to all other submarkets between \( t_o \) and \( t_1 \), \( E^Q_{i1} = \sum_{j \neq i} S^Q_{ij} \).

1) Aggregate new construction at \( i \), \( S^Q_{B_i} \), is available directly from our new construction supply functions for the set of potential builders, where each builder decides on the basis of relative rates of return, simplified as follows:

\[(11) \quad S^Q_{B_i} = S^N(p_i, c_i, (P^{-i}), p, (C^{-i})) \quad \text{where} \quad (X^{-i}) \quad \text{is a vector} \quad (X^j) \quad \text{all} \quad j \neq i\]

\[(13) \quad S^Q_{E_i} = \sum_{j \neq i} S^Q_{ji} = \sum_{z \neq i} S^M_{ji} (p_i, p_j, c_j, (C^j)(P^j), (C^{-j})) \quad \text{all} \quad z \neq i \neq j \]

where \( C_{xy} \) is cost of converting unit from level \( x \) to level \( y \).

4) The number converted from \( i \) to all other levels \( j \), and to abandonment, demolition for new housing construction,* non-housing use, \( S^Q_{E_i1} \), is obtained from aggregating all conversion actions away from \( i \):

\[(14) \quad S^Q_{E_i} = \sum_{j \neq i} S^Q_{ij} + \sum_{k \neq i} S^Q_{ik} = \sum_{i} S^M_{ij} [p_i, p_j, c_j, (C_i^j), (C_{iz})] + \sum_{k} S^M_{ik} (\rho^H, \rho^D)\]
where $i \neq j$; $k =$ abandonment, non-housing use, and demolitions for new housing and other re-uses.

So the total supply of units available at level $i$ in $t_1$ is:

$$S^t_{Q_{t_1}} = S^t_{Q_{t_1}} + S^t_{Q_{t_0}} - S^t_{Q_{t_0}}$$

$t_0$, $t_1$ superscripts indicate the period over which each response occurred.

B. Market Equilibrium

Each quality submarket $i$ clears (partial equilibrium in $i$) when number of housing units with each attribute mix and age demanded equals number supplied at a given submarket price $P$:

$$S^Q(Q_i, R, A)^t_1 + [P_1, (P_i, t_1), (P_i, t_1)] = D^Q(Q_i, R, A)^t_1 + [P_1, (P_i, t_1), (P_i, t_1)]$$

Analogous to short-run market adjustments, prices adjust here in the direction of excess demands:

$$\partial P_i \partial D_i = 0$$

General equilibrium occurs where all quality submarkets clear at a given set of submarket and attribute prices:

$$\partial D_i \partial P_i = 0$$

At general equilibrium, all demanders are satisfied with their choice of quality levels and attribute mix, all builders have chosen their preferred quality level and mix targets, and all existing owners have made the most
appropriate conversion decisions. No agent in the market can improve its situation with respect to consumption, building or conversion.

A divergence from general equilibrium in any one submarket generally requires an adjustment of price in all submarkets, as well generally of attribute prices, each adjustment calling for repercussions from others in a sequence. A mutually compatible adjustment configuration comes about through the typical adjustment convergence of general equilibrium in an economy as a whole because all of the commodities are direct substitutes for one another: non-convergence problems arising from complementarity are absent here. A complication to general equilibrium in our treatment must be noted here. It concerns asymmetry in dealing with adjustment of attribute mix as opposed to quality level.

Structures, in the existing housing stock were built at different times in the past, stretching over a large expanse of time. New structures built at any one time would be expected to have an attribute mix that accommodated closely to the contemporary set of relative attribute prices - reflecting both production cost conditions and demand taste factors stemming from demographic characteristics of the population - so that (18a) holds:

\[
(18a) \quad \frac{MC_{hp}}{MC_{hs}} = \frac{P_r}{P_s}
\]

but houses built at earlier times may have attribute mixes that do not fully accord with subsequent attribute prices. To see this, begin the stock at some time \( t_o \), adjusted to equilibrium prices, \( (p)_o \).
Now, with the passage of time, production and taste factors change, and thereby, through market clearing, relative attribute prices change also. Three types of adjustment occur. Consumers change their desired housing configurations to satisfy:

\[
(18b) \quad \frac{U_{hr}}{p_r} + \frac{U_{hs}}{p_s} = \frac{p_r}{p_s}
\]

for the new \( p_r, p_s \). Abstracting from any supply response this is accomplished by shifts by households among the numerous, highly varied, existing stock, mutually advantageous shifting being guaranteed so long as there is taste heterogeneity among households. Such shifts alone, however, are not likely to reattain general equilibrium. They will be abetted by supply-wide responses through both new construction and conversion.

New units built in each new period can be completely adjusted to whatever new set of attribute prices exists in that period, since profit maximization requires fullfillment of \((18a)\), and technology is always available to make this possible. Because of the small numbers of newly built units relative to the existing stock, this too is not generally sufficient to produce general equilibrium in attribute mix. Conversion of existing units is the third adjustment forthcoming. Owners of existing units modify their units to bring attribute mix in closer accord with new attribute prices. Here is where the asymmetry lies. The technical constraints of existing units, in conjunction with conversion technology, often do not permit full adjustment to satisfy a conversion form of \((18a)\). Instead, many owners are trapped in corner solutions. So, for example, if it seems that \( \frac{u_r}{u_s} \) is too
small in a given house, considering \( \frac{P_r}{p_s} \), the owner has no incentive to correct it: it is too expensive to increase \( h_r \) and too expensive to decrease \( h_s \). Architecture, basic layout, materials, etc. cannot feasibly be changed substantially. A consequence of a less desired relative, even absolute, attribute mix is a decline in market-perceived quality. Yet despite suffering a loss in market value, the owner may be in equilibrium without "full" attribute adjustment because he can do no better at given quality and attribute prices. So there are two sorts of discontinuity: one, the combination of quality and attribute prices may have to change appreciably before some attributes will be changed at all, or significantly; two, some attributes cannot effectively be modified beyond a certain degree, so both absolute and relative changes may be bounded.

So the difference between quality level and attribute equilibrium is that while consumers, new builders and owners of existing units are all presumed to be capable of smooth pinpointed equilibrium adjustments for quality level disequilibria, only the first two are presumed to be so capable for attribute adjustment: owners of existing units may be trapped with discontinuities. In the latter case, therefore, the passage of time may find other structures, still within the threshold of incomplete adjustment, possessing attribute mixes increasingly different from those being newly constructed. Such discontinuities throw heavier responsibility on new construction and consumer shifts to achieve a general equilibrium.

In what follows we shall be concerned with the characteristics of general equilibrium for new construction and conversion. To simplify the
analysis for convenience, we shall speak primarily of quality level equilibrium, but this is not meant to preclude attribute mix equilibrium. The treatment of quality level has its close counterpart in attribute mix, and should be so understood. For the section where we examine systematic differences between new construction and conversion, we have already indicated the most salient difference under attribute equilibrium: namely, that new construction achieves precise, continuous adjustment whereas conversion is limited to discontinuous, incomplete adjustment, thereby placing major responsibility for equilibrium adjustment not only on new construction but also on significant consumer shifting among units.

C. Properties of General Equilibrium

The aggregate supply to any quality submarket \( i \) includes four types of decision: new construction, conversion from \( i \) elsewhere, conversion from elsewhere to \( i \), and retention at \( i \). In making this decision each such decision maker has reconciled various possible tradeoffs with alternative decisions that might have been made. Moreover, each type of decision maker is competing against every other sort of decision maker as well as against every other decision maker of the same type.

For every new builder, a decision to build at level \( i \) instead of \( j \) implies that the revenue tradeoff for \( i \) relative to \( j \) is at least as favorable as the marginal cost tradeoff between them. Since we are abstracting from attribute mix adjustment, it is convenient to express the revenue tradeoff directly in market value terms. Let \( N7(H) \) be the function showing market value in each quality submarket. Thus:
(20) \[ \frac{MV_i}{MV_j} > \frac{MC_i}{MC_j} \]

If all new builders are essentially similar in technology, information, etc., the fact that some build at i and some at j then implies that under competition prices and costs adjust as a result of the adjustment of relative numbers of units constructed at i and j so that the revenue tradeoff exactly equals the marginal cost tradeoff i.e.,

(21) \[ \frac{MV_i}{MV_j} = \frac{MC_i}{MC_j} \]

In addition to inter-submarket balance, each act of new construction balances the attractiveness of investment in housing relative to non-housing opportunities. Repeating our earlier condition, the number of new units built equalizes a declining rate of return with number (due to upward pressure on building input prices and credit constraints) against the opportunity cost of capital to housing.

Conversion supply also provides units at these quality levels. Even more literally than for new construction, each existing unit will be shifted to - or retained at - one and only one quality level destination. The optimal shift for each unit therefore involves an inequality similar in spirit to eq.(20).

There are five cases to consider - two upgrading, two downgrading, and retirement of the given structure from housing. Consider some \( H_i, H_j \) such that \( H_i < H_j \); therefore \( MV_i < MV_j \).

A. **Upgrading via physical improvement**

(22) \[ \Pi_{ij}^{I} = MV_j - MV_i - C_{ij}^{I} > 0 \]
No owner will convert a unit from \(i\) to \(j\) unless \(\Pi^I_{ij} > 0\). Of course, for given unit \(\alpha\) actually to shift from \(i\) to \(j\) means that \(j\) is the best destination for \(\alpha\): i.e.,

\[
\frac{\alpha \Pi^I_{ij}}{\alpha c_{ij}} = \alpha \rho_{ij} > \alpha \rho_{ik} \quad \text{all } k \text{ (including all housing retirement options as well as all other quality levels)}.
\]

b. **Upgrading via consolidating**:

The gain from such conversions is given by:

\[
\Pi^II_{ij} = \Pi^II_{MV,j} - m^II_{MV,j} - c^II_{ij} > 0
\]

where \(m_j\) is number of units in structure after conversion from \(i\) to \(j\)

\(m_i\) is number of units in structure before conversion from \(i\) to \(j\)

\(m^II_j < m^II_i\)

The higher unit market value at \(j\) over \(i\) must be more than enough to offset both the smaller number of units and the cost of the conversion, if \(i\) is to be shifted to \(j\). Again, actual shift requires a large enough \(\Pi^II_{ij}\) so that the rate of return exceeds that of all other options, including retirement-analogously to eq. (23).

C. **Downgrading via splitting**

The gain from such conversions is:

\[
\Pi^III_{ji} = m^III_{MV,i} - m^III_{MV,j} - c^III_{ji} > 0
\]

\(m^III_i > m^III_j\),

This issue here corresponds to that for consolidation.
d. **Downgrading via undermaintenance**

The gain from such conversions is:

\[(25) \ Pi_{ji} = [C_M(H_j) - C_M(H_i)] - C_T(H_j - H_i) - (MV_j - MV_i) > 0\]

Here the source of potential gain is that maintenance expenses will be lower at \(H_i\) than at \(H_j\). The costs of achieving the saving are the loss of market value in downgrading quality plus the time cost of lagged adjustment \((C(H - H_i))\). Converting from \(j\) to \(i\) requires that \(Pi_{ji} > 0\), and \(\rho_{ij}\) exceed that for any other conversion option.

What do these conditions tell about price relations between and among different quality submarkets? At inter-submarket equilibrium, no gain can be obtained from making further conversions. This is shown by

\[\Pi_I = \Pi_{II} = \Pi_{III} = \Pi_{IV} = 0\]

in \((22)-(25)\), and translates into the following conditions:

\[(27) a. \ MV_j - MV_i = C_{ij}^I\]

\[b. MV_j - MV_i = C_T(H_j - H_i) - [C_M(H_j) - C_M(H_i)]\]

\[c. MV_j - MV_i = \frac{C_{ij}^I}{m_{ij}^I} + MV_i\left(\frac{m_{ij}^I}{m_{ij}^I} - 1\right)\]

\[d. MV_j - MV_i = \frac{C_{ij}^I}{m_{ij}^I} - MV_i\left(\frac{m_{ij}^I}{m_{ij}^I} - 1\right)\]

\(MV_j - MV_i\) and, as the next section will explain, all the right hand sides are a function of the number of units converting from either \(i\) to \(j\)
or j to i. In a. \( \frac{\partial c_{ij}}{\partial e_{ij}} > 0 \). In b. \( \frac{\partial c_{M(j)}}{\partial e_{ij}} < 0 \), so RHS rises.

In c. \( \frac{\partial c_{ij}^{III}}{\partial e_{ij}} > 0 \), so RHS rises. In d. \( \frac{\partial c_{ij}^{III}}{\partial e_{ij}} < 0 \), so RHS rises.

Thus, for any initial incentive to convert between i and j, successive conversions will increase the cost of upward conversions and decrease the gains of downward conversions. This alone may stop them at an equilibrium.

If not, the increasing numbers in the destination submarket and decreasing numbers the origin submarket will change \( MV_j - MV_i \) so as to decrease the gains of upward conversions and increase the costs of downward conversions. If equilibrium occurs while there are still units at both \( H_i \) and \( H_j \), then (27a-d) shows the characteristics. If either \( H_i \) or \( H_j \) is exhausted before equilibrium is reached, the inequalities of (22)-(26) show the condition.

Conditions (27a-d) indicate that more than one kind of conversion from \( H_i \) to \( H_j \) may be occurring simultaneously, more than one kind of conversion from \( H_j \) to \( H_i \) - and that both conversions from \( H_i \) to \( H_j \) and from \( H_j \) to \( H_i \) may be occurring simultaneously. This is because conversion costs of each type depend on characteristics of individual units (houses), so the conversion costs of a marginal converter depend on the identity of that converter, and this in turn depends on how many lower cost converters have already converted. So it is the relative numbers of converters of any type in any direction that adjust to bring about the equilibrium (along with, of course, adjustment of relative prices \( MV_i \) and \( MV_j \)). These considerations apply for every pair of submarkets, \( H_i \) and \( H_j \).
Now extend the analysis to a third submarket, \( H_k \), for which \( H_k < H_i < H_j \).

A unit at \( H_k \) may be converted to either \( i \) or \( j \), with \( C_{ki}, C_{kj} \) as conversion costs of type I conversions respectively. Market values are \( MV_k, MV_i \) and \( MV_j \). As such, this problem is similar to that of new construction, and the optimizing solution is the same: if \( \frac{C_{ki}}{C_{kj}} > \frac{MV_i - MV_k}{MV_j - MV_k} \) it will shift to \( j \). Suppose a number of such units, facing \( \frac{C_{ki}}{C_{kj}} > \frac{MV_i - MV_k}{MV_j - MV_k} \), move to \( i \).

Then \( \frac{C_{ki}}{C_{kj}} \) will rise, along with a smaller tendency of \( \frac{MV_i - MV_k}{MV_j - MV_k} \) to fall.

As the shift to \( i \) continues, \( \frac{C_{ki}}{C_{kj}} \) eventually equals \( \frac{MV_i - MV_k}{MV_j - MV_k} \) and the shift to \( i \) stops. The same process occurs if the shift began from \( k \) to \( j \). So equilibrium shifting from every level \( k \) to each pair of potential destinations requires:

\[
(28) \quad \frac{C_{ki}}{C_{kj}} \left( \frac{S_{ki}}{E_{ki}} \right) = \frac{MV_i - MV_k}{MV_j - MV_k}
\]

for all levels \( k \) from which units are actually shifted to \( i \) and \( j \) in equilibrium. Condition (28) says essentially that the marginal rate of transformation via conversion equals the marginal rate of substitution in use. As such it is intrinsically the same as the equilibrium condition for new construction between any two submarkets, as given in eq. (21). Moreover, the conditions given in (23)-(26), and (27), can be put into a three submarket form that also essentially says that all forms of conversion are
balanced where the marginal rate of transformation to any pair of alternative destinations equals the common marginal rate of substitution.

Relative prices for the set of quality submarkets are determined, therefore, by three groups of decision-makers:

1) marginal users of housing reach equilibrium choices for each pair of quality submarkets such that relative market prices equal marginal rates of substitution (infra-marginal users, not poised on the margin between any two, satisfy an inequality);

2) new builders reach equilibrium choices for each pair such that relative prices equal relative marginal building costs;

3) groups of owners of each kind of existing unit select among possible shift destinations such that relative price changes from given origin levels equal relative (complex) costs involved in converting units to the different submarkets. All three groups interact competitively; prices are determined by their interaction, not by the decisions of any one group. In general, the demanders' marginal rates of substitution for any pair of quality levels are not constants; they vary with relative numbers of units consumed by the population: i.e., they are a variable for each household and a variable across different households. Also, relative marginal builders' costs may vary with relative numbers of units built at different levels, due to differences in input pressure if builders specialize in construction at different levels. (Hitherto we have assumed away explicit systematic differences among builders.) Finally, because of the structural differences among existing units of any origin quality level, conversion costs to different destination levels for the marginal shifters will vary with total number of shifts of each type from this origin to the different destinations.
So any disparity in marginal tradeoff rates (substitution or transformation) among or within the three groups will be rectified by changing relative numbers of occupants or builders or converters: relative numbers and relative prices will simultaneously vary to establish the mutually consistent equilibrium balance overall.

One possible exception to this is if differences among new builders are minimal, especially in regard to building at different quality levels, and building inputs are not specialized for construction at different levels. Then change in absolute numbers of new units under construction may change input prices and so absolute construction costs, but changes in relative numbers of units under construction at different levels will not change relative construction prices at those levels. If so, then the aggregate marginal rate of transformation via new construction between any two levels will be a constant. Under such a situation general equilibrium will require that relative prices for any two quality levels to which new construction contributes in the present period be equal to this constant marginal rate of transformation. Corresponding marginal rates of substitution by demanders, and relative conversion costs where conversion supply contributes to those quality levels in the present period, must vary till they equal this same rate via changes in relative numbers.

This fixity of new construction transformation rates gives it a special influence on relative prices. But the power is constrained by the fact that, unlike users and modifiers who are likely to occupy and supply units at all quality levels, new construction may supply units to only a modest subset of quality levels. The very homogeneity of new construction options and
constraints significantly narrows supply decisions relative to the wide disparities among households and existing housing units. As a result, for any of the many pairs of quality levels where new construction does not supply units to both levels, relative prices are determined by interactions among the three kinds of decisions, as in the general case.

C. The Mix between New Construction and Modification Supply at Equilibrium

We now consider in detail the competition among different suppliers. We are concerned about the broad competition between the two major supply modes, new construction and conversion of existing units, and also the competition within the diverse group of converters. We begin by considering the character of equilibrium choice situation to underscore the nature of the competition.

To put into relief the chief kinds of issues we shall abstract again from the equilibrium of attribute mix.

D. 1. New Construction Supply Response

Consider first the rate of return - maximizing choices of individual new builders. Figure 1 shows the perspective of a single builder of new units who takes the cost and revenue functions from new construction as given.
Figure 1

Rate of Return Maximization by Supply Destination for New Construction and Conversion
Alternative quality submarkets are shown on the X axis, logs of total cost and revenue (market value) on the Y axis. The TC function shows the cost of producing a new unit for each possible quality submarket by a representative builder. Since all builders are once again being defined as essentially similar (as opposed to our suggestions in the last section that some builder specialization exists), the TC curve shows the cost opportunities open to all such builders. The MV function shows the alternative market value opportunities that would result from selling a new unit in each quality submarket. The same selling opportunities face all builders who supply a new unit at each point in time.

Rate of return for each such builder is maximized when marginal log TR = marginal log TC.* This occurs locally at both $H^*_1$ and $H^*_2$ and globally at $H^*_2$. But $H^*_1$ may also represent an effective optimum if any supplier specialization exists. $H^*_1$ and $H^*_2$ represent single point optimal submarket destinations for newly constructed units.

Figure 1 shows only one or at most two, submarket destinations for new construction. In an intermediate run situation this could well occur. But equations (6) and (7), and our discussion of the determinants of submarket prices, imply that every pair of destinations supplied by new construction will have equal rates of return. Equalization cannot be brought about by shifts in marginal cost ratios, because, by assumption, in the absence of significant builder specializations these ratios are invariant to relative numbers of new units constructed at the different submarkets. So equalization must come about by adjustment of relative market values in different submarkets. Some such adjustments will occur, destinations with
high construction concentrations experiencing price declines, those with little or no construction experiencing price rises—thereby bringing disparate rates of return closer together. But full equalization requires that absolute numbers of newly built units be great enough to influence all submarket prices sufficiently. In the presence of the competition from large numbers of uneven conversion adjustments, the small absolute number of new construction probably precludes relative price adjustments large and extensive enough to bring many of the submarkets into rate of return equalization for new construction. So even with this more extensive adjustment process, new construction may still end concentrated in only a relatively few submarkets.
A wider spread of optimal building can occur if there is significant builder specialization. If there are persistent grounds on the basis of which building firms specialize in different kinds of houses - where these specializations are related to quality level - then new suppliers become varied with respect to the TC function. Each type of builder has a different TC function but faces the same MV function. Then optimal supply destination(s) will tend to differ for each type of builder. So more destinations become optimal initially, and subsequent adjustment include cost side as well as relative price variations, as differential resources shift among builders with different cost functions. This eases the requirement for MV adjustments alone, and permits wider convergence of rates of return for new construction. Smallness of absolute numbers, and the mobility across specialization niches, still make full convergence of rates of return unlikely. Some continued concentration, and complete absence from some submarkets, remains a highly likely pattern.

D. 2. Conversion Supply Responses

Figure 1 also shows the equilibrium supply destinations of three particular existing units that may be converted, located in submarkets H₂, H₃ and H₄. All owners of existing units, if they modify their units to each alternative quality submarket, can obtain the price shown by the MV function for that quality level. As indicated earlier, each owner will convert his/her unit to another quality level if the resulting percentage gain in market value between origin and destination exceeds the percentage cost of the conversion, or if the percentage loss of market value from the conversion is less than the percentage saving in cost from making the
conversion: i.e., log \( MV_j \) - log \( MV_i \) > \( \Delta C_{ij} \); or:

(29) log \( MV_j \) > log \( MV_i \) + log \( \Delta C_{ij} \) where \( i \) is origin level, \( j \) is destination level. The log MV function thus shows both log \( MV_i \) and log \( MV_j \). Let us now consider the optimal modification choice for units starting at levels \( H_2 \), \( H_3 \) and \( H_4 \). While the log market value attainable by any given shift is shown by the log MV curve, the log cost of each such shift is shown by the log total cost of a converted unit*. In Figure 1 the curve showing what is given up by converting to every other destination from origins \( H_2 \), \( H_3 \) and \( H_4 \) are (log \( MV_i \) + log \( \Delta C_{ij} \)), labeled \( C_{2x}^0 \), \( C_{3x}^0 \), \( C_{4x}^0 \), respectively. The optimal shift for each unit is where the rate of return on a shift is maximized - i.e., where log \( MV_x \) - (log \( MV_i \) + log \( \Delta C_{ix} \)) is maximized. As usual, this occurs in the Figure where the slope of the log MV function equals that of the log \( C_{ix}^0 \) function. This occurs for the \( H_3 \) unit at \( H_3^* \) for the \( H_4 \) unit at \( H_4^* \), and and for the \( H_2 \) unit at \( H_2^* \). Note that the optimal choice for the unit starting at \( H_2 \) is to remain there.

Most important, while new construction will occur at \( H_2^* \) and possibly at \( H_1^* \) as well, conversion supply is likely to occur at a wide variety of submarkets. Generally, although not always, units starting in different submarkets will end at different submarkets. In principle, there may be at least as many destinations as there are origins of existing units (as will be shown below, different units from the same origin may end in different destinations). So supply destinations depend on the origin of existing units. The second characteristic of the outcome is that optimal modification can involve either upgrading (e.g. for the \( H_3 \) unit) or downgrading (for the \( H_4 \) unit). A third characteristic is that a young existing unit with origin at a level which
current market conditions make a desirable destination for new construction (e.g., H₂) is not likely to find any conversion destination preferable to its origin. (But, as we shall see below, an older unit at H₂ may well decide to convert elsewhere.)

The last result, and the specific character of the first two results, stem from the shape of the relevant \( C^{0}_{ix} \) functions relative to the new construction TC function. The relationship is simple: the marginal rate of transformation between any two quality levels is less via new construction than via modification of young existing units. It is more expensive to modify a unit from one level to another, where the original structure exercises various constraints concerning materials, architecture, configuration, size, etc. than is the difference in building cost between those two quality levels via new construction, where capital is completely malleable, and all inputs can be used together without prior constraint in the most efficient way that current technology permits. (Locational premia for land is ignored in this discussion; their inclusion could qualify the proposition). So the family of total cost functions for converted units all have the property that they rise faster between an origin and an upgraded destination, or fall less fast between an origin and a downgrading destination (an exception exists for very old units: see below), than the comparable segment of a new construction cost curve.

The conversion cost functions shown in Figure 1 omit two important aspects of conversion cost that were raised earlier. Unlike what we have characterized as a high degree of homogeneity among new construction firms, the "raw materials" of conversion supply, the stock of existing units, is
notably heterogeneous. Houses differ in terms of age, and in the set of housing attributes. Both have an impact on conversion decisions. While one particular unit with origin at $H_i$ may have modification cost opportunities portrayed by $C_{ix}$ in Figure 1, a different particular unit starting at $H_i$ will have very different modification cost opportunities. So optimal modification may well differ for the two. Without explicitly considering the array of different cost functions it is impossible to predict the number of units starting at each $H_i$ which will shift to each possible destination.

Let us begin with the effect of age. Though houses are very durable in practice (in this model they are potentially eternal), as they age it becomes more expensive to maintain them in any desired condition. Indeed, the cost of upkeep (maintenance/repair) that will maintain them for another period in the quality level at which they began the period - i.e., the "normal" maintenance cost ($C_u(H_i)$) - rises at every quality level, and there is reason to believe that it rises faster with quality. This is shown in eq. (30):

\[(30) \quad a. \quad \frac{\partial C_u(H,A)}{\partial A} > 0, \quad b. \quad \frac{\partial^2 C_u(H,A)}{\partial A \partial H} > 0, \quad c. \quad \frac{\delta^2 C_u(H,A)}{\delta H^2 A} > 0\]

and in Fig. 2.
Figure 2

Effect of Age on Normal Maintenance Costs

where $A_0, A_1, A_2$ show $C_u$ functions for new, moderately old and quite old houses respectively.

Figure 3

Effect of Age on Conversion Cost Functions
where $c_{1}^{k}$ is the total cost of a converted unit from $i$ in upward and downward directions, for age $k$. Age $0 < Age 1 < Age 2$.

The implications of this property for conversions from any given origin can be seen schematically in Figure 3.

Increasing age leads to steeper curves, because the difference in normal upkeep costs increase for all levels, but more for higher than for lower with increasing age (Figure 2).

1) From $H_1$: $H_1^0$, $H_1^1$, $H_1^2$

2) From $H_2$: $H_2^0$, $H_2^1$, $H_2^2$.

Notice that: 1) Optimal conversions are upward for origin $H_1$, downward for origin $H_2$;

2) the older the house, the smaller is the upward conversion, the larger is the downward conversion.

Thus, the non-parallel (non-proportional) rise in upkeep costs biases conversion away from the upward and toward the downward direction. Indeed, in a simple example it can be shown that difference in age can lead to a reversal of conversion direction. If, to highlight the effect of age, one assumes that both the $c_{ix}$ and MV functions are log linear, it is easily proved that: 1) a $\gamma$ percent shift upward or downward are equally as good as remaining at the starting level for a unit of average age (at that origin submarket); 2) a $\gamma\%$ shift upward is preferred to downward or no shift for a unit of less than average age; 3) a $\gamma\%$ shift downward is preferred to upward or no shift for a unit of greater than average age.
Effect of Time Lag Cost of Conversion

where $C_{ix}$ is conversion cost function omitting time lag cost

$L_{ix}$ is conversion cost function including time lag cost

$H_{1^*}$ is optimal conversion destination excluding time lag cost

$H_{1^{**}}$ is optimal conversion destination including time lag cost
Figure 4 differs from Figure 3 in an important way. The cost functions for conversions in Figure 3 reflect only the steeper slopes of upkeep costs by quality for increasing age. They may be linear, although they may not be. Figure 4, however, includes as well the effect of the time lag cost of downward conversion via undermaintenance. Even if differential upkeep costs are linear, thereby encouraging large downward conversions with high age (e.g. via $C_{2x}$), time lag costs rise as the conversion spread between origin and each potential destination rises - so $C_{2x}$ becomes more and more convex away from $H_2$ ($C_{ix}$ relative to $C_{ix}$ in Fig. 4), thereby decreasing the origin-destination distance of the optimal conversion: $H_1^*$ and $H_2^*$ represent smaller optimal conversions from $H_1$ and $H_2$, respectively, than $H_1^*$ and $H_2^*$. In other words, even potentially limitless growing upkeep savings via undermaintenance for very old houses encounter internal limits to optimal downward conversion because of the greater gestation periods required to achieve distant downward targets.

The second aspect omitted from Figure 1 concerns the attribute heterogeneity of the existing stock. Two units of the same age at submarket will rarely possess the same technical capabilities for converting to any particular destination - or even to all other destinations. Their construction materials, architectural configuration, condition, etc. may strongly influence the difficulty - cost - of achieving any, or all conversions. More complexly, one of the units may be easier to convert upward, the other downward. We indicate something of this heterogeneity in Figure 5.
Figure 5

Families of Conversion Cost Function from Given Origin (=H₁)

where α_C, β_C, γ_C, and λ_C are conversion cost functions from origin H₁ for housing units α, β, γ, and λ, respectively
Figure 5 shows that units $\alpha$, $\beta$, $\gamma$, and $\lambda$ — all of the same age and initial quality — have different costs of conversion. It also shows the possibility of asymmetries between upward and downward conversion cost (i.e., the order of the curves upward is not the same as their order downward).

This heterogeneity is important to understanding aggregate conversion. The conversion cost functions in Figure 1 and 4, basic to delineation of optimal conversion, refer only to the conversion of a single unit, positioned at various alternative starting points. But the aggregate situation involves many units starting at each origin. Does the predicted conversion for one unit at each origin remain true for all — or even most — of those at that origin? No. Aggregation adds a critically important factor.

From the array of different conversion cost functions beginning at origin $i$ in Figure 5, we can form an aggregate cost function that shows the cost of converted units from the same origin $i$ to a common destination $j$ as a function of the number of units being converted from $i$ to $j$: Figure 6.

**Figure 6**

Cost of Shift from $H_i$ to $H_j$, as a Function of the Number of Units called in to Shift

$$C_{ij}(Q_{ij})$$

$C_{ij}$

Quantity of units shifting from $H_i$ to $H_j$ ($Q_{ij}$)
At each $Q_{ij}$ the curve $C_{ij}(Q_{ij})$ shows the cost of a converted unit from $i$ to $j$ for the lowest cost converter remaining at $H_i$ after $Q_{ij}$ units have already been converted from $i$ to $j$. Thus, the aggregate conversion process is a sequence in which the lowest cost converter goes first, then the next lowest, etc. Since higher $Q_{ij}$ means that the marginal shifter has higher cost, the $C_{ij}$ curve rises with $Q_{ij}$.

From Figure 6, the least cost of a shift from $H_i$ to $H_j$ would be least where only a small number are asked to shift, because these few are the most capable of being modified from level $i$ to $j$. The larger the number shifting, the higher is the shift cost of the marginal shifter, since the last is less appropriate for the shift. The $C_{ij}(Q_{ij})$ function is therefore a marginal conversion cost function.*

The upward slope of the marginal conversion cost function has important implications for competition among units in different quality submarkets. Suppose MV in a given market varies. At these different prices existing units from several different origins may wish to shift into this submarket. What will determine the origin mix of these? The answer depends on the interplay of "distance" between origin and destination, and number of converters. The two factors have comparable effects on the cost of shifting. Thus, for every origin-destination triple, $H_i, H_j, H_k$, involved in an upward conversion, $(H_i, H_j < H_k, C_{jk} < C_{ik}$ since $H_k - H_j < H_i - H_k$; conversion cost rises with increasing "distance". But also $C_{ik}(H_i, Q_{ik}) - C_{jk}(H_j, Q_{jk}) < C_{ik}(H_i, Q_{ik}') - C_{jk}(H_j, Q_{jk})$, where $Q_{ik} < Q_{ik}'$ and $C_{ik}(H_i, Q_{ik})$ is the marginal conversion cost of a further shift from $H_i$ to $H_k$ when $Q_{jk}$ units have already shifted. Thus, conversion costs rise with
increasing numbers. For undermaintenance conversion, the rate of upkeep saving declines with distance and with number of converters. So a competitive advantage in conversion from given origin to given destination is eroded by increasing numbers of such converters; a competitive advantage for a given number of converters is eroded as an increasing portion of that number come from origins with increasing distance from that destination. The relationship is shown in Figure 7. Ordinates are logs of the variables.

**Figure 7**
Marginal Conversion Costs, and Optimal Shifts, from Different Origins $H_1, H_2, H_3$

For fixed origin and destination, the size of the cost of the conversion (i.e., $\Delta C_{ij} = \log C(H_j) - \log C(H_i)$) of the marginal converter rises with the number of prior shifters ($Q_{xj}$). So each $\Delta C_{xj}$ curve is upward sloping. Since $H_1 - H_j < H_2 - H_j < H_3 - H_j$, $\Delta C_{3j} > \Delta C_{2j} > \Delta C_{1j}$ at every $Q_{xj}$. On the vertical axis we
measure $\Delta MV_{xj} = \log MV_j - \log MV_x$. Since $\log MV_j - \log MV_x$ is the average slope of the log MV function, and $\frac{\Delta C_{xj}}{H_j - H_x}$ is the average slope of the $\Delta C_{xj}$ function, $\frac{\Delta MV_{xj}}{H_j - H_x} = \frac{\Delta C_{xj}}{H_j - H_x}$ is the condition for approximately optimal conversion.

Let the log MV function between $H_j$ and $H_j$ be such that $\Delta MV_{1j}$, $\Delta MV_{2j}$, and $\Delta MV_{3j}$ are as shown in Fig. 7 ($\Delta MV_{3j} < \Delta MV_{2j} < \Delta MV_{1j}$ because $H_j - H_3 > H_j - H_2 > H_j - H_1$). Then at most $Q^1_{1j}$ and $Q^2_{2j}$ units will find it most profitable to shift from $H_1$ and $H_2$ to $H_j$, respectively. No $H_2$ units will find it worthwhile to shift as far as to $H_j$. Suppose now $MV_j$ rises—all other prices remaining unchanged—so that, for graphical simplication, the new set of $\Delta MV$s is $\Delta MV_{1j}^2$, $\Delta MV_{2j}^2$, $\Delta MV_{3j}^2$. (A given rise in $MV_j$ means, of course, a larger shift for low than for high $\Delta MV$ in log space). Then the numbers of optimal shifter to $H_j$ rise from $Q^1_{1j}$ to $Q^2_{1j}$, $Q^1_{2j}$ to $Q^2_{2j}$ and zero to $Q^2_{3j}$. (A rise in several prices together complicates the graphical analysis by requiring comparisons among gains to different destinations. But an interval of $H$ with generally rising prices will attract more shifter as a whole from everywhere else.) Thus, the relative numbers of these shifter to each destination depends on the exact shapes of the $\Delta C_{xj}$ functions and the relative heights of the $\Delta MV_{xj}$ functions. Different shift patterns in the log MV function, or different log C functions, will change the relative sizes of $Q^1_{1j}$, $Q^2_{2j}$, and $Q^3_{3j}$, but will not change the fact that a rise in $\Delta MV_{xj}$ will induce more units to make that shift, and will permit units to shift to $H_j$ from more distant origins (i.e. switch previously zero shifters to non-zero—as here, $Q^1_{3j} = 0$, $Q^2_{3j} > 0$).

Three important conclusions follow from Figure 7: 1) The steeper is the $MV(H)$ function, the greater the distance it will pay to shift a unit to a given destination, and the more units it will pay to shift from each origin to that destination, for a given set of $C_{xi}(Q_{xi})$ functions. 2) The
MV(H) function, the greater the distance it will pay to shift a unit to a
given destination, and the more units it will pay to shift from each origin
to that destination, for a given set of $C_{xi}(Q_{xi})$ functions. 2) The
percentage distribution of origins in a given total of converters to a given
destination will differ for different slopes of the MV(H) function, as well
as for different slopes in the set of $C_{xj}(Q_{xj})$ functions. 3) Distance of
shift and numbers of shifters are competing determinants of the
competitiveness of different conversions.

The analysis of Figure 7 in effect enables us to generate a supply curve
of conversions to each destination. If all $\Delta C_{xj}$ curves are arrayed as in
Figure 7, then, assuming all MV(H) are constant except MV$_j$, each hypo-
thetical MV$_j$ will imply a given set of $\Delta MV_{xj}$, and so lead to a particular
number of desired conversions from each H$_x$. The sum of these is the supply
of conversions to H$_j$ for each MV$_j$. Figure 8 shows this supply function:

Figure 8
Conversion Supply Functions to H$_j$
$S_j$ is a supply curve to $H_j$. It depends on the distribution of existing units at various origins, and on the set of $C_{xj}(Q_{xj})$ functions. What if the rest of the stock were "nearer" to $H_j$? If so, there would be a lower overall aggregate of conversion costs to $H_j$, so a given $MV_j$ would attract more units via conversion and a given change in $MV_j$ would attract more units: i.e., a more elastic supply function. Similarly, if the rest of the stock were "farther" from $H_j$, there would be a higher aggregate conversion cost function to $H_j$, and supply would be lower and less elastic. Curve $S_j(p_I=0)$ reflects supply for a given distribution of the rest of the existing stock. If there were a permutation of this distribution, so that on the average the other units were closer to $H_j$, the supply of conversions to $H_j$ would swing to $S_j(p_I^1)$ - an increase in supply. If, on the other hand, there were a similar but opposite permutation so that on the average the rest of the stock were farther from $H_j$, supply to $H_j$ would swing to $S_j(p_I^{-1})$ - a decrease in supply.

The equilibrium we have characterized depends on a starting distribution of existing units. It thus depends in an important way on a path of adjustment over time. A long-run equilibrium is not supposed to depend on a path of adjustment, but to represent a period long enough for the outcome to be independent of path. In the case of urban housing, however, its durability is so great that to wait for a period long enough for the stock existing at some initial time to have no effect on the character of the "final outcome" could take 50 years or more. It seems suitable to speak of a long-run here in terms of the gestation period of occupancy, building and conversion adjustments in the context of a specific initial stock, rather than to insist on the much longer period beyond which the initial stock would
have no effect (our assumption of "unlimited potential lifetimes" for housing makes this especially questionable). The previous analysis is advanced in this spirit.

D.3. The Equilibrium Mix of New Construction and Conversion Supply to Different Submarkets

We may combine the above analysis of new construction and supply behavior in long-run equilibrium. We draw on our concepts of a supply response by new construction and conversion to different prices in a given submarket to generate the aggregate supply function for each submarket. This is shown in Figure 9:
Figure 9

New Construction and Conversion Supply in a Single Submarket

$S^N$ is the new construction supply curve.

$S^M(p^*)$ are conversion supply curves.

$p=0$ a reference distribution of the rest of the existing stock across different submarkets.

$p_I^j$ a permutation of the existing stock to be "nearer to" $H_j$.

$p_{II}^{-j}$ a permutation of the existing stock to be "farther from" $H_j$.  

At some given price $MV_{jo}$, new construction accounts for $Q^N_{o}$ units to $H_j$, and
conversion (including retention of units at $H_j$) accounts for $Q^M_o$, $Q^M_I$ or $Q^M_{II}$, depending on whether the rest of the stock is in its referential distribution, or closer, or farther, relative to $H_j$. Clearly the total supply to $H_j$, and the mix between new construction and conversion, depends on how "close" the initial distribution of the existing stock is to submarket $H_j$. We can make this explicit by showing the equilibrium process for submarket $H_j$, permitting the difference in total amount supplied to influence submarket price. This is shown in Figure 10.

Figure 10
Equilibrium Mix Between New Construction and Conversion Supply in a Single Submarket
Figure 10 simply shows the same conversion and new construction supply curves as in Figure 9, but added horizontally to form aggregate (new and conversion) supply curves, and superimposed on a submarket demand function (D).

Depending on whether other units in the stock are farther from or nearer to \( H_j \), price falls from \( M.V_{II} \) to \( M.V_{I} \), output increases from \( Q_{II}^M \) to \( Q_{II}^M \), conversion supply numbers increase from \( Q_{II}^N \) to \( Q_{II}^N \), while \( Q^N \) declines from \( Q_{II}^N \) to \( Q_{I}^N \) - a response to declining price. Thus, again, the share of total supply made up by conversion depends importantly on the initial distribution of existing units among submarkets.

The above analysis provides the tools for examining the explicit competition between new construction and conversion as supply modes. We shall apply it in the next section to attempt to incorporate known institutional features of the U.S. situation.

IV The Mix of New Construction and Conversion Supply in Different Submarkets

A. Quality Level Specialization

In the last section we saw how - in a formal way - the mix between new construction and conversion supply is determined in a single submarket. Is this same mix likely to occur in all submarkets, or is the mix entirely stochastic, or are there special forces that make for systematic differences in the mix in different submarkets? We shall now examine this question. In order to give an intuitive characterization of this relationship it is helpful significantly to simplify the commodity/choice space. Instead of a continuity of quality levels we shall deal with only two, Upper Quality and Lower Quality units. This facilitates graphical analysis.
We are interested in the ratio between Upper (U) and Lower (L) units supplied by new construction and conversion. Is there a tendency for these ratios to differ, so that each supply mode specializes in one or the other, or is there no essential difference in mix of submarkets between the two modes? The answer depends on some institutional/technical facts concerning the two modes.

First, in most U.S. cities there are stringent code and zoning restrictions that establish rather high minimum standards for new housing structures in terms of materials, techniques, safety, crowdedness of use, etc. This implies that no truly low quality units can be legally built in each present period. To enter the "low" quality market via new construction requires "overbuilding" - i.e., building features appropriate to higher quality submarkets, but aimed at clients who can only afford prices more appropriate to lower qualities.

Second are features of the cost of maintenance and repair of existing units that we have already described. The cost of maintaining a unit during a given period at the quality level with which it began the period (its "normal maintenance") depends on a number of factors - materials, construction methods, architecture, nature of use, etc., as well as age. Normal maintenance cost rises with age, and very likely disproportionately so for higher quality levels.

The third consideration is that there is asymmetry between upward and downward conversion. While structural change, change in condition of structure, and consolidating of units within a single structure are available to upgrading, downgrading is mostly dependent on change in condition and
splitting of units within the given structure. For upgrading, consolidating has a strong, more flexible rival in structural change, which is akin to, but costlier than, new construction for comparable difference in quality level. For downgrading, splitting has no real structural change rival - and is capable of quicker and more radical change in quality than change in condition, but combinations of the two may be especially effective.

What these factors together imply is that new construction has legal and technological difficulty building at low quality, but downward modification of some kinds of existing structures - especially old, large houses - is very cheap. We attempt to introduce these features into two-dimensional transformation functions.

For new construction the key concept is the need for legal overbuilding in some quality ranges; for conversion it is the effects of age on the patterns of conversion costs and the asymmetries between upward and downward conversion.

Let us begin with code/zoning constraints on new construction. Builders need to overbuild in some quality ranges, but the degree of overbuilding required - or perceived as desirable by builders - is not constant throughout the range. Above some clearly "acceptable" level no overbuilding is required; below some clearly "unacceptable" level no decrease at all in input quantities is permitted if a quality level lower than this is targeted. Between these two boundaries, however, within a "penumbra" of quality levels, the degree of overbuilding is discretionary, depending on builder judgment. Within this penumbra, if progressively decreasing quality levels are targeted, some input savings may be achieved, but not as much as
if no legal restrictions were in effect. Overbuilding therefore occurs within the penumbra, and the degree increases continuously toward the lower boundary, beyond which overbuilding is complete: no further input savings are possible. This is shown in Figure 11.

**Figure 11**

Overbuilding under Code/Zoning Restrictions

The x-axis is the range of quality levels, from lowest ($H^B$) to highest ($H^T$). The y-axis is the ratio of marginal cost of each abscissa quality level $H_i$ to that of the highest level. Moving leftward from $H^T$ shows the input saving obtainable by targeting lower quality destinations. In the absence of builder specialization or other systematic cost differences among builders, we expect the ratio to be a linear function. This occurs from $H^{**}$ to $H^T$. 
Between $H^B$ and $H^*$, legal restrictions are absolute: no input savings are possible for quality levels below $H^*$. Declines between $H^{**}$ and $H^*$ permit nearly normal savings near $H^{**}$ but these decline continuously—degree of overbuilding increases continuously—as $H^*$ is approached. So Figure 11 shows increasingly unfavorable cost tradeoffs as output destinations decline below $H^{**}$.

To translate this essentially multi-quality level property into two quality levels cannot be done completely. But a flavor of it can be retained by the following construction. Suppose we have only two quality level commodities—U and L (upper and lower). A transformation function between them indicates the different combinations of the two achievable from a given total amount of productive resources considering both production and upkeep costs. The slope at any point indicates the number of units of one that must be sacrificed if resources were optimally shifted to give one extra unit of the other. We define the slope of any particular mix, $\frac{U}{L}$, in the two quality level dimensional world as the marginal tradeoff at an isomorphic location on the quality spectrum of the original multi-quality level dimensional world. In effect, we are equating the tradeoffs of "average" aggregate quality with those of an average quality. The correspondence between points in the two worlds is accomplished by the following transformation:

$$\frac{U}{U+L} = \frac{H^*_i - H^B}{H_i^* - H^B}$$

(31)
That is, if, e.g., \( \frac{U}{U+L_i} \) equals 90%, so 90% of total units are Upper, 10% Lower, this point in 2-commodity space corresponds to that location on the multi-quality spectrum which is 90% of the distance from the lowest toward the highest level. The shape of a transformation function will generate a continuous series of unique ratios and so a unique correspondence with the quality spectrum. So the slope of the U-L transformation function at \( \frac{U}{U+L_i} = 0.9 \) is the same as the ratio of marginal costs at \( H_i = H^B + \frac{U}{U+L_i}(H^T-H^B) \). That ratio is given in Figure 11 above. For high values of \( \frac{U}{U+L_i} \), shifts toward lower average quality have linear tradeoffs. They remain linear until "average" quality equals \( H^{**} \) and thereafter the tradeoff worsens: the slope declines in absolute terms until, at "average" quality \( H^* \), it becomes zero. A transformation registering these properties is shown in Figure 12.

**Figure 12**

Aggregate Transformation Function for New Construction in U,L Commodity Space
Here the point \((U^{**}, L^{**})\) corresponds to average quality \(H^{**}\).

A transformation function can be constructed for conversion supply also. Here, too, our construction involves translating situations from the multidimensional world into two dimensions, and here too the translation captures only a flavor of the issue. But the flavor suffices to enable us to characterize systematic differences between new construction and conversion.

We begin with an initial distribution of units across the different quality levels, and a set of conversion cost functions. The initial distribution gives us a weighted mean quality level. This becomes translated into a point in \(U-L\) space in the same manner as with new construction (i.e., via \(\frac{U}{U+L}\)).

The set of conversion cost functions, together with the distribution of units, generate submarket supply curves where the "prices" in each are essentially ratios of Market Values across submarkets. The meaning of the transformation function tradeoff is the new "price ratio" which will attract enough additional units in the desired direction (i.e., toward \(U\) or \(L\)) so as to change the weighted average designated by the "unit change" in \(U-L\) space.

The unfolding shape of the transformation function depends on how easy it is to elicit net changes in relative submarket supplies. For a unit move in \(U-L\) space there are many possible combinations of multiple submarket shifts involving upward and downward conversions, that will achieve the appropriate change in weighted mean quality. Each is associated with a new set of submarket prices, and so a new weighted mean price ratio (using initial mean price as base). So the slope itself a mean "price ratio" that will elicit the relevant supply quantities — unlike for new construction where it represented relative costs — but this is really an opportunity cost notion also.
The character of the shape of the conversion transformation function is determined by the fact that each move can come about through the competition among innumerable suppliers with a wide variety of slightly differing cost circumstances. Small moves in either direction in U-L space should thus be essentially continuous and without great changes in shape. In orientation toward the U and L extremes, conversion costs for upward conversions to high quality levels are likely to rise faster than for upward conversions to more modest quality levels, since the cost of making the conversion itself may be comparable for equal upgrading - but the differentially greater upkeep costs add more to the cost of converted units at very high levels than to lower levels. This factor makes downward conversions to very low quality levels asymmetrically attractive relative to upward conversions to very high levels. So if the transformation has a tilt, it is to make higher and higher quality levels more difficult to attain - i.e., a steeper slope as high U/L is approached.

Figure 13
Upper-Lower Quality Mix for New Construction and Conversion
Let us superimpose both new construction and conversion transformation functions in the same space to draw inferences about the respective quality specializations of the two supply modes. Figure 13 shows upper-lower quality mix for new construction and conversion. 

\( T_N, T_M \) are the transformation functions for new construction and conversion, respectively. Their shapes conform to the arguments given above. Their intercepts are the general equilibrium values determined as described above.

Suppose the initial distribution of existing units is at \( M_0 \). Now let the equilibrium price ratio be \( \left( \frac{P_L}{P_U} \right)_1 \). This is shown by the parallel lines \( \left( \frac{P_L}{P_U} \right)_1 \). This price ratio elicits equilibrium new construction supply at \( N_1 \), and conversion supply at \( M_1 \) - a shift of the latter from \( M_0 \) to \( M_1 \). It is clear that conversion supply produces a ratio of \( L \) to \( U \) (angle \( \Theta_M \)) greater than that of new construction (angle \( \Theta_N \)), despite the fact that starting point \( M_0 \) represents a lower ratio than \( N \). Rotating \( \frac{P_L}{P_U} \) slightly rightward - to indicate a slightly more favorable price for \( U \) relative to \( L \) - would shift \( M \) slightly to the right along \( T_M \), but it would make \( \frac{P_L}{P_U} \) parallel to \( T_N \) and shift \( N \) radically rightward along \( T_N \), indicating extreme specialization of high quality units (suggested by the less extreme equilibrium, \( (M_2, N_2) \)). One does not have to believe in strict linearity for so large an interval of \( T_N \) to appreciate that even modestly favorable prices for upper quality would result in substantial specialization to high quality units.

This analysis is meant to suggest strongly that new construction will generate higher \( U/L \) mixes than will conversion, regardless of starting mixes. Since the two modes are competitive, and the equilibrium price ratio partly reflects this competition, it is to some extent the superior strength of new construction at upper qualities that drives conversion largely elsewhere, and similarly the superior strength of conversion at lower qualities that drives new construction largely elsewhere.
In Figure 13, $M$ represents a high L/U ratio even though $M_0$ represented a much lower ratio. Does this mean that initial distribution of units does not influence conversion equilibrium? No. Initial distribution has an important influence on the equilibrium. It does so by helping to determine the very shape of $T_M$ (and therefore the location of tangency with price curves), as well as its equilibrium intercepts. Conversion supply curves to the various submarkets - as we saw earlier - depend significantly on initial distribution, because this influences the $C_{ij}(q_{ij})$ functions on which conversion supply depends.

B. Determination of General Equilibrium Prices

In the preceding sections we assumed an equilibrium set of submarket prices and analyzed how builders of new units and converters would respond. Now we shall examine how these equilibrium prices are obtained through the interaction of demand and the two supply modes. We simply make graphic our treatment above. This is shown in Figure 14.

Figure 14

Equilibrium Price and Quantity-Low Units
The functions \( D(MV_{U1}) \), \( D(MV_{U2}) \) show the demand for low quality units when the price of upper quality units is \( P_{U1}, P_{U2} \), respectively, where \( MV_{U1} > MV_{U2} \). Since \( U \) and \( L \) units are substitutes, the higher is the price of \( U \), the greater will be the demand for \( L \). The character of this demand is explained generally in section II above.

The functions \( S_n(MV_{U1}), S_m(MV_{U1}), S_{M+N}(MV_{UL}) \) are the new construction, conversion and aggregate supply functions, respectively, when the price of \( U \) units is \( P_{U1} \). \( U \) and \( L \) are substitutes not only in consumption but also in production, as our treatment of supply makes clear (since each submarket competes with every other as possible construction or conversion destinations). So the higher the price of \( U \), the lower will be the supply in \( L \). Thus, \( S_{M+N}(MV_{U2}) \) is the aggregate supply of units to \( L \) when the price of \( U \) is \( MV_{U2} \): since \( MV_{U2} < MV_{U1} \), \( S_{M+N}(MV_{U2}) > S_{M+N}(MV_{U1}) \). Substitutability in demand has opposite effects on quality than substitutability in supply. The supply functions are generated by the process discussed above.

For any given price of \( U \) we can define both demand and supply for \( L \).

For \( MV_{U1} \), equilibrium in the \( L \) market gives \( Q^*_{L1} \) as aggregate equilibrium quantity, \( MV^*_{L1} \) as equilibrium price, and a supply mix of \( M_{Q^*_{L1}} \) and \( N_{Q^*_{L1}} \) for conversion and new construction. For a lower price of \( U \), \( MV_{U2} \), supply shifts outward, demand shifts inward, and price falls (to \( MV_{L2}^* \)) as a result of both; but aggregate quantity is the net effect of the opposing forces on quantity, and could go either way. In Figure 14, it is shown at \( Q^*_{L2} \), decreasing from \( Q^*_{L1} \) - but this movement results from the specific \( D \) and \( S \) shifts arbitrarily chosen. At the new equilibrium there will generally be a different ratio of \( M_{Q^*} \) to \( N_{Q^*} \).
A comparable analysis of the U market would show that in general the equilibrium mix between U and L quantities, as well as the relative contribution of the two supply modes, would differ with different prices of U.

C. Inter-Submarket Convergence of Prices

The above analysis shows that if equilibrium price in one submarket assumes a certain value, equilibrium price in the other submarket will adjust to it, and vice versa. There is no unique pair of prices at this stage of inter-market equilibrium. But if we start with a given price in market 1, price in market 2 will adjust to it. Then price in market 1 will adjust to that price, and market 2 will adjust again. Thus, an interactive process occurs. Will the process converge to a set of prices that reciprocally support one another and bring about no further change?

We turn to this problem of general equilibrium in conclusion. Figure 15 shows the analysis.

Figure 15

Inter-Market General Equilibrium
The problem is the familiar one of conjectural variation. MEC_L (Market Equilibrating Combination) is the locus of market clearing combinations of MV_U and MV_L from the point of view of the L submarket adjustment; i.e., for each value of MV_U, MEC_L shows the value of MV_L which achieves equilibrium in submarket L. Similarly, MEC_U is the equilibrium adjustment locus for submarket U. Both functions are upward sloping, because U and L are substitutes.

The relative steepness of MEC_L and MEC_U depends on the demand and supply elasticities - direct and cross - for both U and L. As drawn in Figure 15, the intersection of the two curves represents a stable general equilibrium: \( \hat{MV}_U, \hat{MV}_L \). This is because stability requires - as is satisfied here - that each change in one market elicit a subsequent price change in the other which is less than the prior change, whichever is the market that changes first. If the elicited change exceeds the prior change, the relative slopes of the two curves are reversed, and the system becomes unstable: once dislodged from the intersection, subsequent inter-market reverberations lead to wider and wider swings, never returning to the intersection.

V. Application of the Model to Public Policy Concerns

This has been a long excursion into supply relationships. At the outset I motivated it heavily in terms of an ability to illuminate important public policy issues. It would, of course, greatly exceed the scope of this paper to attempt any kind of detailed, let alone comprehensive application of the model to policy considerations. Nevertheless, some brief indication is called for about what kind of input the model can have for policy analysis.
I conclude by sketching three types of role the model can play in this regard.

A. Policy Instruments and Impact Mechanisms

Many policy instruments have been used or proposed to achieve goals of public intervention. Among them are land assembly subsidies, tax abatements on new construction, loan availability and subsidization for construction or rehabilitation, zoning and code regulations, rent control, income tax benefits for homeownership. Moreover, each of these has numerous variants. The mechanism by which the instruments influence housing market outcomes differ markedly, and their per unit impact on these outcomes differ even more, when the many variants of each are taken into account. The first role that the model here discussed can play is to clarify exactly what is (are) the mode(s) by which each instrument transmits its effects into the housing market. Once such modes are identified, a qualitative version of the model can sometimes indicate unambiguously what is the direction of impact of some given instrument. More usually the complexity of the overall model will not permit unambiguous prediction of direction, but only conditional predictions given certain parameter ranges.

Quantitative versions of the model, however, can in principle make point and interval predictions of policy outcomes. Since the relational web operating in the housing market complex is so involved, such predictions are most unlikely to be intuitively accessible, so it is a most important achievement to be able to achieve them (assuming, of course, that the model is both salient to the problem and effectively quantifiable).
B. Maximization of Net Impact

Use of most policy instruments will have both a direct and an indirect effect. The direct effect is the impact on those whose behavior is directly linked to an incentive or constraint which is changed by the use of the instrument. The indirect effect is the response made by private agents to the market changes brought about by the direct effects. It is often the case that the indirect effect is in the opposite direction to that of the direct effect, so, since the direct effect is generally in the direction required for achievement of the goals of policy intervention, the indirect effect is a leakage from, or offset to, the policy's intentions.

Instruments will often differ in the extent to which they provoke indirect offsets. Since they also differ in the size of their direct effect per unit, the net effectiveness of the instruments will tend to differ as well. The size of the intended direct effect will not be a dependable measure of the instrument's overall impact. Indeed, where direct impacts are approximately equal, policy choice should depend on the size of the indirect effect. More than this, some instruments may provoke indirect offsets so great as largely to wipe out favorable direct effects. They are notably inefficient instruments - at least in certain circumstances. One characterization of such instruments is that they "play against the market" - that is, they affect private market incentives in such a way that private agents attempt to recover a balance upset by the policy intervention. An example of the kind of mechanism that is involved is where public policy simply adds a certain number of new housing units in a particular submarket without arranging for a new price structure that will tend to support the new
supply balance among submarkets - or actually changing relative prices to make the new balance even more at variance with these prices than if prices had remain unchanged. Then private builders will tend to direct fewer new units to the submarket in question, owners of units at other submarkets will convert fewer units to the submarket, and owners of units at the submarket will convert more units out of the submarket, than if the new units had not been added exogenously. In such circumstances the stable remaining net additions of units to the targeted submarket may be substantially fewer than were directly added by government policy.

The model sketched above can aid policy makers to fashion policies - especially in the form of policy packages - that do not play against the market, that instead use market forces to support or even augment direct effects. The model can show the pattern and intensity of indirect effects to different types of intervention, and so facilitate selection of intervention components that complement, rather than rival, one another in these regards. It is arguable that the history of U.S. housing policy is rife with cases of sizable leakages bleeding away the effectiveness of policy, or even of multi-part interventions where different components had contradictory effects, in effect canceling one another out. Use of the above model even in qualitative form can alert policy makers to avoid such sources of ineffectuality, as well as to aid the search for positive mutual reinforcement.

C. Targeting Program Benefits Appropriately

Except as part of macroeconomic counter-cyclical policy, housing policy goals rarely concern total housing, or the price of housing, or housing
welfare for all. Rather, they concern housing problems for particular
groups, or problems with respect to particular kinds of housing, or in
particular neighborhoods. Housing policy goals are targeted, sometimes very
precisely. The formulation of program packages to hit these targets squarely
is not a trivial task. The model presented here shows how many kinds of
interactions, linkages, spillovers, offsets occur in response to any
perturbation of the system. Moreover, it suggests that many policy
instruments will have significantly uneven incidence across the housing
specific market complex. This is important because central to the model is
that the distribution of direct impacts is a critical (although not
exclusive) determinant of the final consequence to the system. So the
ability to pinpoint policy targets successfully requires understanding many
of the complex interactions of the system.

That such understanding is not to be lightly attributed to policy-makers
is suggested by the many studies of public program which condemn the programs
for having distributions of benefits and costs very wide of the program
intentions. The present model can play an important role in clarifying the
distribution of positive and negative consequences across the population and
the various portions of the housing spectrum for each hypothetical public
policy package. It can be so used to help assemble components into packages
that efficiently target the designed policy aims.

For this role too, what can be accomplished depends on whether the
qualitative version of the model is used, or one with extensive
quantifications of parameters. For a complicated system the latter is always
a more powerful analytic tool. But some of the qualitative demonstrations of
this paper suggest strongly that for policy makers even to be just aware of
the existence of some of the non-intuitive relational linkages would help to
avoid some of the more horrendous errors of public policy in the housing
field. Imaginative application of the qualitative model alone should make a
real difference in the quality of policy-making.
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