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The Future of Housing in the United States: An Econometric Model and Long-Term Predictions for the 2000 RPA Timber Assessment

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Abstract

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This paper reports a structural model of the U.S. housing sector that was used to generate the key housing assumptions used in the 2000 Resources Planning Act timber assessment: number of households, improvement expenditure, and square footage of new residential construction by unit type. Assuming average annual population growth of 0.77 percent and real income growth of 1.99 percent, the model predicts 1.30 percent average annual growth in housing investment, compared to 2.04 percent annual growth since 1952. The allocation between new construction and home improvement remains fairly constant at about 56 percent and 44 percent, respectively. Scenario analysis was used to test sensitivity of the predictions to key macroeconomic assumptions.

Keywords: Housing demand, housing supply, residential construction, maintenance and remodeling of housing, structural models.

Summary

This paper reports a structural model of the U.S. housing sector and the model predictions for 1996 through 2050 that provided the basis for housing assumptions in the 2000 Resources Planning Act (RPA) timber assessment. This is the first time that RPA housing assumptions have been based on a structural model explicitly linking the related housing demand and supply behaviors so that the resulting housing predictions are internally consistent. Assuming average population growth of 0.77 percent per year and real income growth of 1.99 percent per year, the model predicts that the number of households will grow at an average annual rate of 1.07 percent (compared to 1.81 percent per year since 1952), constant dollar housing investment will grow at an average annual rate of 1.30 percent (compared to 2.04 percent per year since 1952), and square footage of new residential construction will grow more slowly at an annual average rate of 0.89 percent because of the aging population and assumed increases in building site prices. Alternative scenarios were used to explore the sensitivity of the model predictions to the underlying macroeconomic assumptions. Assumptions for income growth appeared to be very important for improvement expenditure and for square footage of new construction of single-family units. Population growth assumptions appeared to be important for the number of households but less important for housing investment and new construction. Labor and wood prices appeared to be important for the allocation of housing investment between new construction and improvement. Building site price had important effects on the amount of square footage of new construction per dollar of new construction and on the allocation of new construction between single- and multiple-family housing units. This model incorporated several advances in structural modeling of the housing sector, and it will provide a basis for further analysis to improve our understanding of the fundamental housing market relations.

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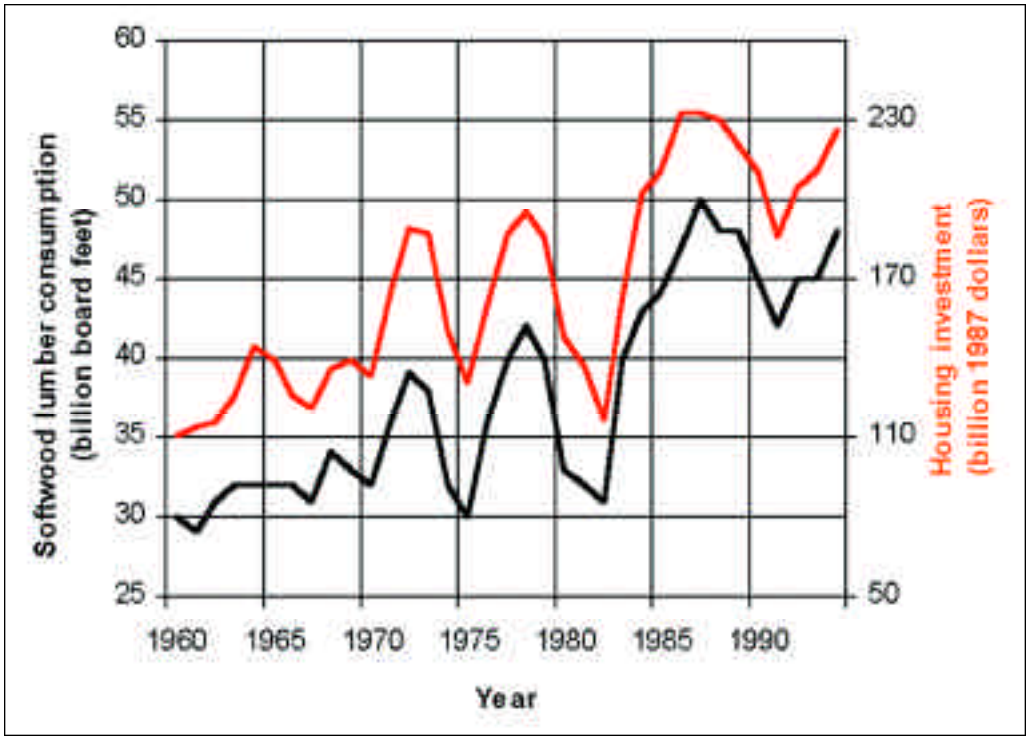

Figure 1—Softwood lumber consumption and constant-dollar quantity of housing investment by new construction and improvement.

Introduction

Residential construction dominates demand for solid wood products in the United States; it accounted for 72 percent of all softwood lumber and 75 percent of all structural panel consumption in the United States in 1996 (McKeever and Anderson 1993). Cycles in housing markets have been closely linked with cycles in wood products markets. Figure 1 shows how parallel softwood lumber consumption and new residential construction and improvement expenditures have been since 1960. Figure 2 shows the procyclical movement in real softwood lumber prices in the 1970s, early 1980s, and 1990s.[1] Analysis of long-term trends in wood use and wood prices in the United States, such as that required under the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, as amended by the National Forest Management Act of 1976, must necessarily involve analysis of housing markets.

In past RPA timber assessments, the components of housing market activity were predicted separately by using trends, links to income, housing starts accounting models, and constant proportions assumptions for household consumption behavior. Preliminary predictions were offered for review and adjusted in response to expressed concerns. The final predictions could be said to represent a synthesis of “conventional wisdom” and simple modeling.

[1] In the late 1980s, softwood lumber prices likely were affected by a timber supply shift resulting from high real interest rates, which led to low softwood lumber prices in spite of high levels of housing activity

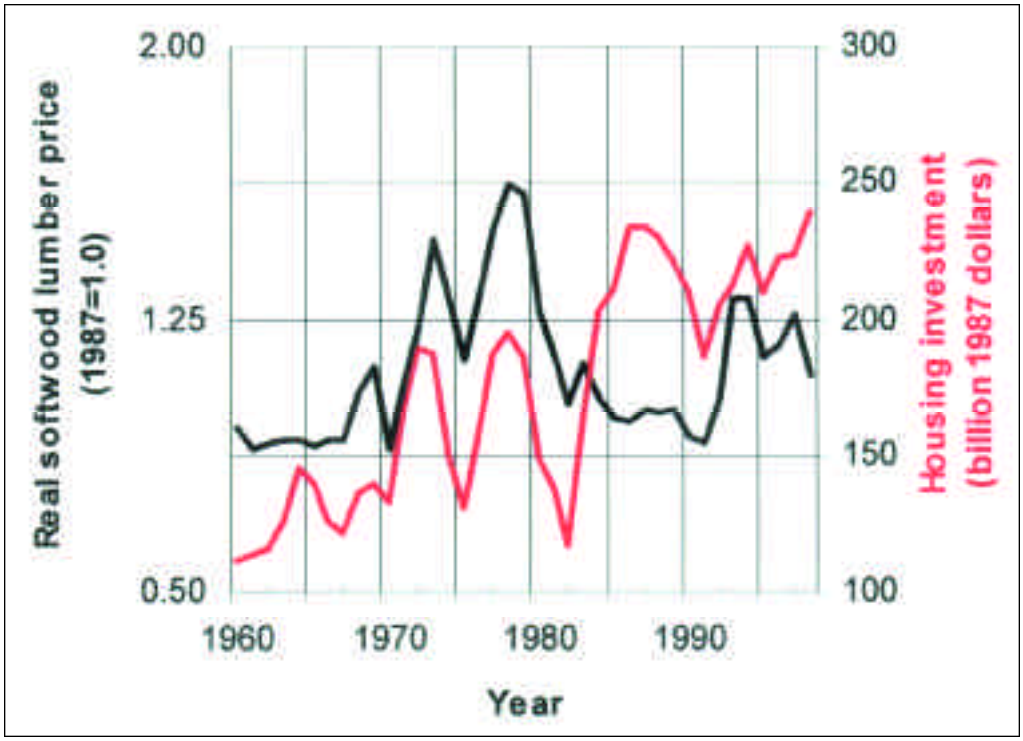

Figure 2—Real softwood lumber price and constant-dollar quantity of housing investment by new construction and improvement.

For the current RPA timber assessment, housing predictions were generated from a structural model of the U.S. housing market—an updated and extended version of the preliminary model reported in Montgomery (1996). The model predicts the number of households, the constant dollar levels of investment in new residential construction and in improvement of the existing housing stock, and square footage of new residential construction by unit type (single- and multiple-family units). Because observers of housing markets are more familiar with housing starts and average unit size predictions, a simple ad hoc model was constructed to illustrate how the square footage predictions might be disaggregated into those units.

The econometric approach taken to modeling the housing sector in this RPA timber assessment bases predictions of future behavior on observations of past behavior. This backward-looking approach has limitations. Predictions based on assumed values of explanatory variables that fall outside the range of the sample from which the model was estimated are spurious. But the housing predictions necessarily depend on values for exogenous variables well outside their historical ranges. For instance, household income is expected to rise to unprecedented heights, and mature adults are expected to form a larger component of the population than ever before owing to their increased longevity and to overall reduced fecundity. Also, because some potentially important structural changes cannot be observed, such as innovations in technology and changes in preferences, they must be omitted from the model or implicitly assumed to remain constant.

The past, however, is the best available lens through which to view the future. Structural models, estimated econometrically, provide a systematic way to organize information about past behavior to deduce future trends. Hence, they are useful for the scenario analyses that allow policymakers to consider implications of different policy scenarios. Structural models impose consistency on the set of interrelated predicted variables via a model structure based on economic theory so that if, for instance, predictions for the general economy suggest increased investment and income growth, the housing sector model will predict increased investment in and consumption of housing services and the corresponding level of construction activity.

This paper reports the structural model of the U.S. housing sector and the model predictions of housing market activity for 1996 through 2050 that provided the basis for housing assumptions in the 2000 RPA timber assessment. From macroeconomic assumptions developed by the U.S. Department of Agriculture, Economic Research Service,[2] and population projections developed by Day (1996) at the U.S. Department of Commerce, Bureau of the Census, the model predicts that (1) the number of households will grow at an average annual rate of 1.07 percent, faster than the 0.77-percent average annual growth rate for the total population, but slower than the historical (1952-95) average annual growth rate of 1.81 percent; (2) investment in housing (measured in constant dollars) will grow at an average annual growth rate of 1.30 percent compared to a historical rate of 2.04 percent; (3) square footage of new residential construction will grow more slowly at an annual average rate of 0.89 percent because of the aging population and assumed increases in building site prices; and (4) single-family housing units will account for a slightly increasing share of total new construction as the young adult component of the population diminishes in relative importance.

The Model

The basic structural model is composed of a set of behavioral equations describing demand and supply in the U.S. housing sector. Its theoretical development is described in detail in Montgomery (1996). The version reported in this paper was estimated with updated data; the predictions reported here are therefore somewhat different from those reported previously. The basic model predicts constant housing investment in 1987 dollars. Constant dollars are a commonly used measure of homogeneous units of capital stock.

Models of derived demand for wood in housing (see Adams and Haynes 1980) traditionally use a measure of housing investment—square footage of new construction—that is more closely related to wood use than to constant-dollar housing investment. Hence, the basic model was extended in this study to include equations for square footage of new construction by type (single- or multiple-family units) as attributes of new construction.

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[2] U.S. Department of Agriculture, Economic Research Service. 1996. U.S. macroeconomic projections to 2045. Unpublished manuscript. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, OR 97208-3890.

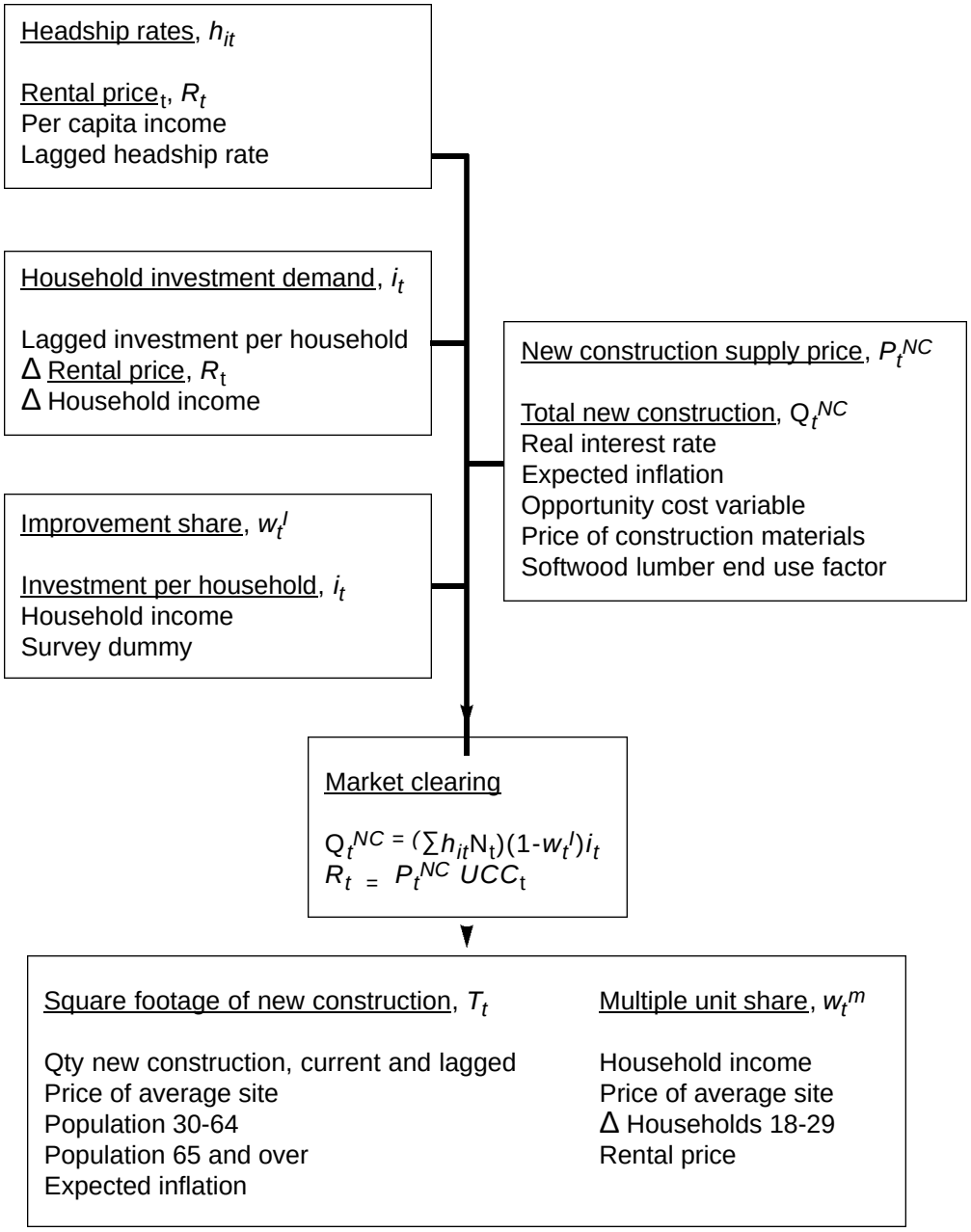

Figure 3—Model components and links. Endogenous variables are underlined.

Model components are illustrated in figure 3 and described briefly below. Endogenous variables are underlined in figure 3 and in the equations. The variables in the model are described in the next section.

In the basic structural model, the demand portion has three main components: household formation, individual household demand for housing investment, and allocation of that investment between new construction and improvement. These housing demand behaviors are separate because they may be affected differently by variations in economic variables but are related because they affect one another. The basic structural model is closed with a new construction supply price equation. The number of households by age group, the constant-dollar value of investment in housing by new construction and by improvement, and the price of new construction are endogenous and are determined by the equality of supply and demand in the market for new residential construction.

The demand portion of the model is a synthesis of two approaches to modeling of housing markets that appear in the housing economics literature. One emphasizes household formation as the main determinant of housing demand (Maisel 1963), and the other emphasizes individual household demand for housing stock (Muth 1960). Because aggregate housing demand depends on both the number of households and the amount of housing demanded by each household, this model treats them as separate but related choices.

The Maisel approach often is used to predict long-term trends in housing starts. The number of housing starts is set equal to the change in the number of households as adjusted by changes in the number of vacant units, discards of obsolete units, and units added by conversion from other uses (e.g., Marcin 1978, Montgomery 1989). Although in this model the number of housing starts is treated as an attribute of new construction, household formation is modeled by age-specific headship-rate equations similar to those used by Marcin, Montgomery, and also Smith (1984) and Smith and others (1984). Headship rate is the proportion of the population in an age group that identify themselves as heads of households. In the logit model, individuals choose to head a household if the value of an unobservable index variable that is a linear function of exogenous variables exceeds some threshold value for that individual. Because data are reported in proportions rather than by individual 0/1 binary choices, the grouped logit model was used. If the probability of that occurrence follows a logistic cumulative density function, the natural log of the odds is equal to the index variable plus a random error, u_{it}, (Judge and others 1982):

$$\ln\left(\frac{\underline{h_{it}}}{1 - \underline{h_{it}}}\right) = \alpha_i \underline{R_t} + X_t^{D\,\prime}\,\beta_i + u_{it} \qquad (1)$$

where $\underline{h_{it}}$ is the headship rate for the ith age group at time t, $X_t^{\ D}$ is a set of exogenous demand shifters, and α_i and β_i are coefficients to be estimated. In the logit model, headship rates are constrained to fall within the unit interval.

The rental price of housing, $\underline{R_t}$, is the cost of holding a unit of housing stock for one time period and is the relevant demand price:

$$\underline{R_t} = \underline{P_t^{NC}}\, UCC_t \tag{2}$$

where $\underline{P_t^{NC}}$ is the price of new residential construction, and UCC_t is the user cost of capital for homeowners and depends on nominal interest rate, property tax rate, marginal income tax rate, expected inflation, depreciation rate, and expected rate of real appreciation in the price of new residential construction (Hendershott and Shilling 1982). The total number of households, $\underline{HH_t}$ is:

$$\underline{HH_t} = \sum \underline{h_{it}} N_{it} \tag{3}$$

where N_{it} is the population in the ith age group at time t.

The Muth (1960) approach is based on microeconomic theory of the household. Utility maximizing households hold housing stock both for the stream of benefits generated and as a component of wealth. When the desired level of housing stock changes in response to changes in demographic attributes of the household or economic variables, households adjust their housing stock by either moving or improving. The adjustment is partial, rather than full, because of moving, information, and other transaction costs. The resulting model consists of a partial stock adjustment equation for housing stock and a share equation explaining the proportion of the adjustment that, on average, is accounted for by improvement of the existing stock. Individual household demand for investment in housing, i_t, is given by:

$$\begin{aligned} \underline{i_t} &= \mu^{NC} \text{ë} H_t^{NC} - (1 - \delta) H_{t-1} \text{û} + \mu^{I} \text{ë} H_t^{I} - (1 - \delta) H_{t-1} \text{û} \\ &= \alpha \underline{R_t} + X_t^{D'} \beta - (1 - \delta) \mu H_{t-1} + u_t \end{aligned} \tag{4}$$

in which investment is the sum of new construction, *NC*, and improvement, *I*. Each of these are some proportion, μ^{NC} or μ^{I}, of the difference between the desired level of housing stock, H_t^{NC} or $H_t^{\ I}$, and current housing stock, $(1-\delta)H_{t-1}$, depreciated from the previous period at rate δ. The desired level of housing stock and the proportion of desired adjustment differ for new construction and improvement because the slope of the budget constraint and the magnitude of transaction costs are different for each

mode of housing investment (see Montgomery 1992). Again, α and β are coefficients to be estimated, and u_t is the random error. The value $(\alpha R_t + X_t^{D\prime}\beta)$ replaces $\mu^{NC}H_t^{NC} + \mu^{I}H_t^{I}$ and μ replaces $\mu^{NC} + \mu^{I}$.[3] Because of strong multicollinearity between housing stock and household income (one of the X^D variables), the equation was estimated in the following form derived from equation (4):[4]

$$\underline{i_t} = \alpha(\underline{R_t} - R_{t-1}) + \text{ë}X_t^D - (1-\delta)X_{t-1}^D\text{û}'\beta + (1-\mu)(1-\delta)i_{t-1} + v_t \qquad (5)$$

where $v_t = u_t - (1-\delta)u_{t-1}$ and X_t^D is the set of exogenous demand shifters.

The improvement-share equation is:

$$\underline{w_t^I} = \frac{\mu^I\text{ë}H_t^I - (1-\delta)H_{t-1}\text{û}}{\underline{i_t}} = \alpha_i\underline{i_t} + \alpha_R\underline{R_t} + X_t^{D,S\prime}\beta + u_t \qquad (6)$$

where α_i, α_R, and β are coefficients to be estimated and u_t is the random error. The share equation was new to structural models of housing demand in Montgomery (1996) and was based on previous work that explored the nature of the budget constraint facing households (Hausman 1985, Hausman and Wise 1980, Montgomery 1992).

The improvement-share equation may be viewed as a reduced-form equation in two ways. First, it represents improvement as a household production process in which the household acts as a contractor. Hence, the improvement-share equation is a reduced-form equation that includes both demand and supply shifters, $X_t^{D,S}$, supply and demand behaviors are not separately identified, and the price of improvement is implicit—i.e., determined by the cost of inputs (labor, wood, and materials) and the price of the substitute (new construction). Second, there is potential for biased coefficient estimates because only households choosing to improve have positive improvement expenditures. This bias can be corrected when cross-sectional data are used and individual expenditure can be predicted (Montgomery 1992). This model, however, uses aggregate time-series data to predict aggregate behavior. Hence, the model coefficients represent the effect of variation in exogenous variables on both the likelihood that individual households will improve and the level of investment of individual households.

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[3] The proportion coefficients, μ^{NC} and μ^{I}, are separately identified only under the special condition that H_t^{NC} is equal to H_t^{I}, a condition unlikely to occur because transaction costs and marginal costs for new construction and improvements are likely to differ.

[4] Equation (5) is derived from equation (4) as follows
By definition, $H_{t-1} = (1-\delta)H_{t-2} + i_{t-1}$. Substitute in equation (4) for H_{t-1} to get:

$$i_t = X_t'\beta - \mu(1-\delta)\left[(1-\delta)H_{t-2} + i_{t-1}\right] + u_t$$

From equation (4):

$$i_{t-1} = X_{t-1}'\beta - \mu(1-\delta)H_{t-2} + u_{t-1} \quad \Rightarrow -\mu(1-\delta)H_{t-2} = i_{t-1} - X_{t-1}'\beta - u_{t-1}$$

Substitute for $-\mu(1-\delta)H_{t-2}$ and rearrange to get equation (5).

A linear function was used for the share equation, although it does not confine predicted shares to the unit interval. This is of little practical concern, however, because there are no observations in the sample near the 0/1 bounds; in fact, the observations fall between 0.25 and 0.50.

Together, the three equations represent aggregate demand for new residential construction and for improvement:

$$\underline{Q_t^I} = \underline{w_t^I}\ \underline{HH_t}\ \underline{i_t}, \qquad \underline{Q_t^{NC}} = (1 - \underline{w^I_t})\ \underline{HH_t}\ \underline{i_t} \tag{7}$$

The price for new construction, $\underline{P_t^{NC}}$, and the quantity of new construction, $\underline{Q_t^{NC}}$, are set in the market for new construction by the equilibrium of supply and demand. In earlier studies, modelers of housing markets often imposed a form of recursiveness to avoid simultaneity (see for example, Smith 1984, Topel and Rosen 1988); in this model, the current price of new residential construction is explained by a supply price equation and is determined simultaneously with the quantity of new construction:

$$\underline{P_t^{NC}} = \alpha\, \underline{Q_t^{NC}} + X_t^{S\,\prime}\, \beta + u_t \tag{8}$$

where X_t^S is a set of exogenous supply shifters.

The value of the housing stock, measured in constant dollars, represents the ability of the housing stock to produce housing services. But that value is a function of the attributes of the housing stock including the size and type of the dwelling unit, the number of stories and rooms, the type of heating and plumbing, roofing and siding materials, and more. Additional inputs to the production of housing services that are not part of the housing stock itself include the building site, neighborhood characteristics, and environmental amenities.

Wood use for a given level of investment in new construction depends on the attributes of that new construction. The two attributes explained in this model, square footage of new construction and its allocation by unit type, have traditionally been used to drive derived demand for wood in new residential construction (e.g., Adams and Haynes 1980). The more square footage per dollar invested, the more wood is used. And more wood is used per square foot in single-family units than in multiple family. The trend in the last 45 years has been decreasing square footage of new construction per dollar invested (from 22 square feet per thousand dollars in the 1960s to 19.5 in the 1990s), leading to less wood used per dollar invested. Unit type also matters; in 1995, about 7.0 board feet of softwood lumber was used per square foot of new single-unit construction and 4.8 board feet of lumber per square foot of multiple-unit construction (Resources Information Systems 1996). Multiple-unit construction reached a peak of importance in the early 1970s and has been diminishing relative to single-family units ever since. Several factors suggest themselves as

potential drivers of these trends. Income growth leads to more investment per household, but there may be diminishing marginal returns to unit size. Demographics also may play a role, with size being most highly valued during the family-raising middle years. Finally, increasing land cost may discourage sprawling homes and encourage multiple-unit construction.

Square footage of new residential construction, T_t, was modeled here as a reduced-form function of the quantity of new construction as explained in the basic model, $\underline{Q_t^{NC}}$, and a set of supply and demand shifters, $X_t^{D,S}$. These include sociodemographic variables and prices of other inputs (most particularly, the building site price):

$$T_t = \alpha \underline{Q_t^{NC}} + X_t^{S,D\,\prime} \beta + u_t \tag{9}$$

A share equation was used to explain the allocation between multiple, *m*, and single, *s*, unit structures:

$$w_t^m = \alpha \underline{Q_t^{NC}} + X_t^{S,D\,\prime} \beta + u_t, \quad w_t^s = 1 - w_t^m \tag{10}$$

Data and Estimation Results

The version of the model reported here provided the housing assumptions for the 2000 RPA timber assessment. The model was estimated as a single system by iterative three-stage least squares using EViews (Quantitative Micro Software 1997), with the full set of exogenous variables in the model serving as instruments.

The structure of the model is complicated by the presence of right-side variables that are nonlinear functions of both endogenous and exogenous variables: household income, the rental price of housing, and the quantity of new residential construction. Consequently, the rank and order conditions for identification in the classical linear model do not apply. The necessary and sufficient conditions for identification are given by Brown (1983) and were satisfied by the equations of this model.[5] Also, the variables in the logit equations for headship rates were transformed to correct for known heteroskedasticity; the variance of the error term is $\{1/[N_{it}h_{it}(1- h_{it})]\}$.

[5] Brown's condition is stated in a corollary to his theorem 1 that the ith equation is identified if and only if the rank of the matrix $[Q'|\Phi_i]$ is at least N-2, where Q' is a matrix of the partial derivatives of each variable in the model with respect to the exogenous variables (expression 3-2 in Brown), Φ_i is a matrix consisting of the restrictions on parameter values, and N is the number of variables in the model including those that are nonlinear functions involving endogenous variables. In this model, N is 39; there are 8 basic endogenous variables (price of new construction, household investment in housing, improvement share of investment, headship rates for three age classes, square footage of new construction, and multiple-unit share of square footage of new construction), 5 nonlinear functions of endogenous variables (rental price of housing, total new construction, household income, change in the rental price, and change in household income), and 26 exogenous variables, including the constant.

Table 1—Coefficient estimates for headship-rate equations (t-statistics in parentheses)

Variable	Young adults, 18-29 yr	Middle agers, 30-64 yr	Mature adults, 65+ yr
Constant	-0.363 (3.45)	0.003 (0.12)	-0.037 (0.92)
Rental price	-0.252 (1.87)	0.004 (0.05)	-0.043 (0.24)
Per capita income	11.007 (3.34)	0.756 (0.40)	10.528 (2.47)
Lagged headship	0.777 (12.5)	0.920 (14.8)	0.741 (9.30)
Adjusted R^2 statistic[a]	0.959	0.973	0.942
Durbin's h-statistic[b]	0.87	0.42	0.75

[a] R^2 statistic is computed for levels of headship rates, rather than transformed for logits of headship rates. These give the proportion of the variation in the headship rates themselves that is explained by the regression.
[b] Durbin's h-statistic substitutes for the Durbin-Watson test for 1st-order serial correlation in the residual in the presence of a lagged dependent variable. It is distributed standard normal. The null hypothesis that there is no serial correlation cannot be rejected at the 5-percent significance level if Durbin's h-statistic is below 1.96.

Price expectations play a role both in housing demand (via the user cost of capital for homeowners) and new construction supply. This model used quasi-rational expectations, in which expectations depend on both current and past values. Expectations for inflation were estimated by using a polynomial distributed lag model based on Modigliani and Shiller (1973).[6] Expectations for the growth rate in the real price of new construction were an average of the growth rate in the previous three years.

Annual data for 1952-95 were used and sources are described in the appendix. Estimation results for the headship-rate equations are shown in table 1. Estimation results from equations for household investment demand, improvement share, and

[6] The procedure involved estimating the weights in an equation setting the current long-term nominal interest rate equal to a weighted average of future short-term nominal interest rates, which because they are unknown, were represented by a weighted sum of past real short-term rates plus a weighted sum of past inflation rates The second sum is a model of expected inflation. The model estimated here imposed a fourth-order polynomial-distributed lag structure on 3-month Treasury bill rates and quarterly inflation for 20 lagged quarters, and it included dummy variables to account for seasonal variation and the variance in short-term rates for the last two years to represent risk. The long-term rate was the 10-year Treasury bond rate. The estimated lag weights for inflation were used to construct the expected inflation variable used in the housing model equations. Estimation results are available from the author.

Table 2—Coefficient estimates for household investment demand, improvement share, and new construction supply price equations (t-statistics in parentheses)

Equation	Coefficient
Household investment demand equation:	
Constant	0.018 (0.05)
Rental price for housing, differenced	1.403 (1.25)
Household income, differenced	0.258 (8.34)
Household investment, lagged	0.554 (6.57)
Proportion in 18-29 age class	2.788 (2.58)
Survey dummy	-0.060 (1.21)
Adjusted R^2 statistic	0.65
Durbin's h-statistic[a]	1.57
Improvement share equation:	
Constant	0.425 (3.89)
Household investment	-0.088 (8.11)
Rental price for housing	-0.275 (1.70)
Household income	7.73e-03 (5.23)
Proportion in 18-29 age class	0.407 (1.94)
Survey dummy	-0.053 (8.29)
Wood price index	-0.260 (8.36)
Materials price index	0.306 (3.43)
Carpenters' wage index	-0.208 (3.95)
Adjusted R^2 statistic	0.87
Durbin-Watson	2.04
New construction supply price equation:	
Constant	0.170 (3.54)
Total new construction	1.30e-06 (11.5)
Expected real interest rate	1.127 (5.42)
Expected inflation	2.295 (14.9)
Expected opportunity cost	0.614 (5.81)

Table 2—Coefficient estimates for household investment demand, improvement share, and new construction supply price equations (t-statistics in parentheses) (continued)

Equation	Coefficient
Materials price index	0.202 (4.83)
Softwood lumber use index	0.053 (11.9)
Adjusted R^2	0.90
Durbin-Watson	1.72

[a] Durbin's h-statistic substitutes for Durbin-Watson test for 1st-order serial correlation in the residual in the presence of a lagged dependent variable. It is distributed standard normal. The null hypothesis that there is no serial correlation cannot be rejected at the 5-percent significance level if Durbin's h-statistic is below 1.96.

Table 3—Coefficient estimates for square footage of new construction and multiple-family unit share equations (t-statistics in parentheses)

Equation	**Coefficient**
Square footage of new construction equation:	
Constant	686.245 (0.81)
Quantity new construction	2.32e-02 (21.0)
Quantity new construction—lagged	-5.22e-03 (5.47)
Real site price index	-940.746 (6.02)
Percent of population 30-64	11.515 (0.87)
Percent of population 65 and over	-31.987 (1.51)
Expected inflation (percent)	76.663 (5.31)
Adjusted R^2 statistic	0.94
Durbin-Watson	1.69
Multiple unit share equation:	
Constant	-2.862 (7.16)
Quantity new construction	6.74e-06 (2.48)
Rental price	5.882 (3.36)
Household Income	-50.743 (2.66)
Change in 18-29 year households, lagged 3-year. average	18.403 (9.93)
Real site price index	2.001 (6.26)
Adjusted R^2 statistic	0.72
Durbin-Watson	1.35

new construction supply price are shown in table 2. Estimation results from equations for square footage of new construction and multiple-family share are shown in table 3. The equations, variables, and estimation results are described individually in the following sections for headship rates, household housing investment demand and improvement share, new residential construction supply price, and square footage of new construction by type.

Equations for Headship Rate

The endogenous variables in the headship-rate equations (equation 1) are the headship rates (the number of households headed by a member of age group *i* as a proportion of the population in age group *i*) and the price of new residential construction, $\underline{P_t^{NC}}$, a component of the rental price of housing (equation 2). The exogenous demand shifters, $X_t^{\,D}$, consist of the user cost of capital, which is a component of the rental price of housing; per capita real disposable income; and lagged headship rates for each age group. There were three age groups: young adults of 18 through 29 years, middle agers of 30 through 64, and mature adults of 65 and over. Although finer disaggregation is available in the data, this grouping has some intuitive appeal, and these three age groups are those most discussed in the housing industry literature, although the 30 through 35 year olds often are combined with the young-adult group (e.g., Belsky 1990, 1992; Belsky and Hartwigsen 1992).

The coefficients for the rental price of housing were positive and marginally (10 percent) significant for the youngest age group, and yielded some evidence that increases in the rental price discourage household formation in that age group. Increases in per capita income seem to encourage household formation in the young adult and in the mature adult age groups. The middle age group seems relatively unresponsive to fluctuations in economic variables in its household formation behavior. The coefficients on lagged headship rate are greater than 0.70 and highly significant, thereby indicating that household formation behavior responds sluggishly to changes in exogenous variables.

Equation for Household Investment Demand and Improvement Share

The endogenous variables in the equation for household investment demand (equation 5) are average household investment in housing, $\underline{i_t}$, measured in 1987 dollars; the real price of new residential construction, $\underline{P_t^{NC}}$, which is a component of the rental price of housing; and the number of households, $\underline{HH_t}$, which is a component of household income. The set of exogenous demand shifters, $X_t^{\,D}$, consists of average household investment in housing lagged one year; the user cost of capital, which is a component of the rental price of housing; real disposable income, which is a component of household income; proportion of the population in the young-adult age class; and a dummy variable described in detail below. Both rental price and household income are differences from the depreciated previous year value. The gross depreciation rate, δ, was assumed to be 2 percent (Margolis 1982).

The coefficients for lagged household investment and household income are highly significant, indicating that they are powerful determinants of household investment demand. Together they account for over 60 percent of the variation in levels of investment. The rental price of housing seems to have little explanatory power. And

investment appears to be higher when the young-adult proportion of the population is relatively large. The coefficient on lagged household investment indicates that μ, the proportion of desired adjustment in housing stock that households undertake in one year on average, is about 44 percent.

The endogenous variables in the improvement share equation (equation 6) are the proportion of investment in the housing stock that is accounted for by improvement, $\underline{w_t^I}$; the current level of household investment in housing, $\underline{i_t}$; and the number of households, $\underline{HH_t}$, which is a component of household income. The exogenous demand and supply shifters, $X_t^{D,S}$, consist of real disposable income, which is a component of household income; the rental price of housing; the proportion of the population in the young-adult age class; a set of real input prices (wood, building materials, and labor); and a dummy variable equal to 1 in the years 1961 through 1984.

The dummy variable represents the years when the Survey of Residential Alteration and Repair (SORAR) was used to estimate improvement expenditures for all property owners. Until 1961, estimates of household improvement expenditure were constructed from a variety of sources. After 1984, estimates for homeowners were based on the Consumer Expenditure Survey (CES) and SORAR continued to be used for rental properties. A comparison of the two surveys for six quarters of 1980-81 showed CES estimates for owner-occupied one- to four-unit residential properties were 35 percent higher than SORAR estimates. Significantly more households reported small jobs in CES than in SORAR, while reports of the number of large jobs differed little.[7] In 1984, the two surveys overlapped; reported levels of improvement expenditures obtained from CES were 16.5 percent higher than those obtained from SORAR for owner-occupied properties (U.S. Department of Commerce 1985, 1986). The significant and negative coefficient estimate for the survey dummy suggests that estimates of improvement expenditure might have been, on average, 14.6 percent higher during the dummy period had CES been used. In fact, the jump in reported improvement expenditures in 1984 fueled discussion about the growing importance of improvement as a source of demand for wood. This analysis indicates that part of the jump was an artifact of changing survey methodologies.

The coefficient estimate for household investment was negative. This indicates that improvement is the more stable component of investment in housing. Improvement involves smaller transaction costs than does new construction, because the former does not involve moving. It is therefore less likely to be postponed. The income coefficient estimate is positive and significant, suggesting that increases in income encourage improvement relative to new construction. Again, the rental price of housing seems to have little effect on housing investment choices. The input costs, however, do appear to be important; higher prices for labor and wood seem to discourage improvement relative to new construction, which would be expected if improvement was relatively labor- and wood-intensive.

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[7] U.S. Department of Commerce, Bureau of the Census. 1984. Unpublished internal memo. On file with: U.S. Department of Commerce, Bureau of the Census, Construction Statistics Division, Washington, DC 20233-6900.

Equation for New Construction Supply Price

The endogenous variables in the supply price equation (equation 8) are the real price of new construction, $\underline{P_t^{NC}}$; the number of households, $\underline{HH_t}$; the improvement share, $\underline{w_t^I}$; and constant-dollar household investment in housing, $\underline{i_t}$. All are components of the quantity of new construction, $\underline{Q_t^{NC}}$ (equation 7). The exogenous supply shifters, X_t^S, consist of the real interest rate, expected inflation, an opportunity cost variable equal to the difference between the expected real appreciation rate in the price of new residential construction and the real interest rate, the real price of construction materials, and an end use factor for lumber in residential construction.

The highly significant coefficient for $\underline{Q_t^{NC}}$ suggests that new construction supply, while not perfectly elastic, is highly elastic—averaging 8.17 over the sample period.[8] Previous estimates for elasticity in the new residential construction supply range from perfectly elastic (Follain 1979, Montgomery 1989), to highly elastic (Follain and Velz 1995, Montgomery 1996), to moderately elastic (DiPasquale and Wheaton 1994). In one study, Blackley (1999) found new construction supply to be elastic when estimated using levels but inelastic when estimated using first differences to account for nonstationarity in the data series. Montgomery (forthcoming) found, though, that new residential construction supply is highly elastic regardless of whether the equation was estimated in levels or in differences.

The coefficient estimates for the cost variables in the final model (the real interest rate measures the cost of capital to the builders, and the construction materials price index measures cost of materials) are highly significant and have the expected positive sign. The opportunity cost variable represents alternative investment opportunities for the builder. If the real rate of return on housing is expected to be high relative to the cost of capital, builders more likely will hold new construction for future sale in anticipation of that return.

The coefficient on expected inflation is troublesome. It is positive and significant, suggesting that builders respond more strongly to changes in the nominal interest rate than theory predicts. This result appears in other studies of new residential construction supply; the questions raised by it are well articulated by Topel and Rosen (1988) and remain unresolved.

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[8] The own price new construction supply elasticity was computed at the sample means for P^{NC} and Q^{NC} as:

$$\in = \frac{\partial Q^{NC}}{\partial P^{NC}} \frac{P^{NC}}{Q^{NC}} = \frac{P^{NC}}{\alpha_q Q^{NC}}.$$

Although this form of the supply elasticity, estimated by using a price-dependent form for the supply equation, is analytically equivalent to that obtained using a quantity-dependent supply equation, empirically the two estimates may differ owing to stochasticity.

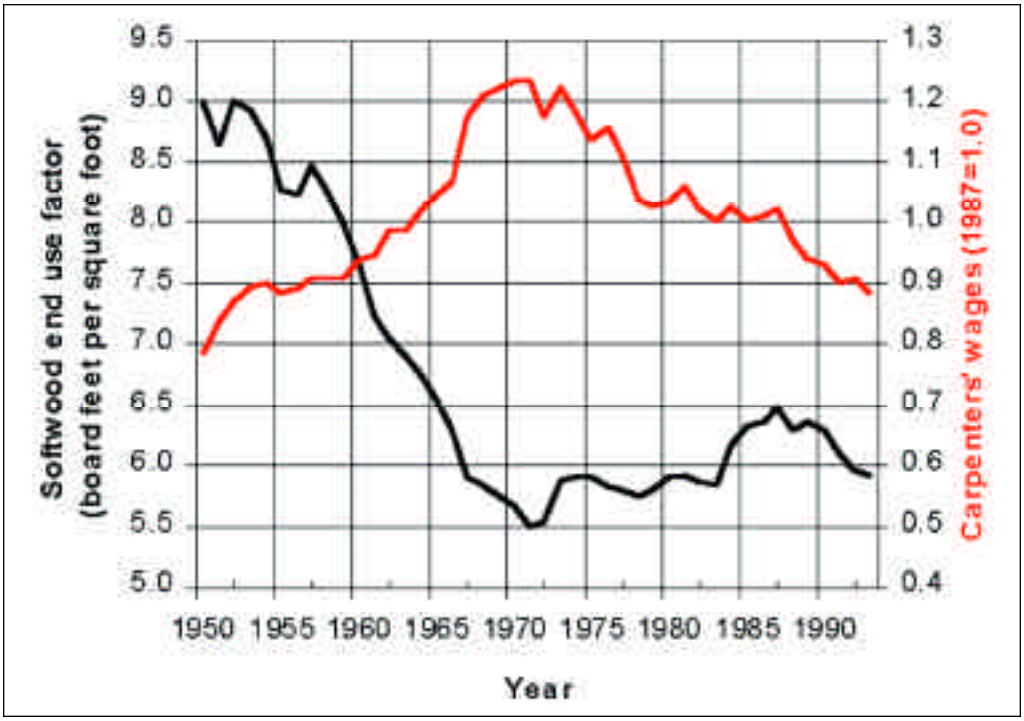

Figure 4—Carpenters'wage index and softwood lumber end use factor.

Normally, labor cost would appear as a cost variable in the new construction supply equation. In earlier versions of this model, its coefficient estimate was negative and significant (Montgomery 1989, 1996), thereby implying that more expensive labor reduces the cost of building. Other studies obtained similar results (Blackley 1999, Follain 1979). This result likely was due to labor-saving technological change that has occurred during the last 50 years; the marginal product of labor has increased while the marginal cost of residential construction has fallen. Once technological change was included in the model, the coefficient estimate for labor cost, although still negative, became insignificantly different from zero and was omitted from the model. The F-test value for the omitted variable test for that variable was 2.76, less than its 5-percent critical value of 4.08. The end use factor for lumber in residential construction (the number of square feet of lumber used per square foot new construction) was used in this model to represent one of the most important of the labor-saving technological changes that has occurred: the substitution of structural panels (first plywood and, more recently, oriented strand board) for lumber in many uses. Figure 4 illustrates the negative correlation between wages for carpenters and lumber use. The highly significant, positive coefficient estimate for the softwood lumber end use factor suggests that substitution of structural panels for lumber has, indeed, reduced building costs. The difficulty is that the end use factor represents a change that has already occurred and is probably close to complete; although it is useful for explaining the past, it is less useful for predicting the future. Most studies employ a

simple time trend to represent diffuse technological change, but that explains little. The underlying assumption is that technological change will continue at a constant pace in the future as it has in the past. This is an area of research meriting further attention. Examples of creative approaches include Spelter's (1984, 1985) innovative, but structurally weak, models representing technology change as a price-sensitive diffusion process.

Equations for Square Footage of New Construction and Unit Type

Square footage of new construction and its allocation by housing unit type are not simultaneously determined in this model. Their equations were included in the system estimation because of potential contemporaneous correlation of the error terms. The exogenous variables in the square footage of new construction equation (equation 9) include the quantity of new construction for the current and one lagged periods, $\underline{Q_t^{NC}}$ and $\underline{Q_{t-1}^{NC}}$; a real building site price index; the proportions of the population in the middle and mature adult age groups; and expected inflation. The quantity of new construction is the main driver in this equation, with the remaining variables explaining deviation of the trend in square footage of new construction from the trend in quantity of new construction.

The coefficient estimate for the building site price index is highly significant and negative. This result conforms to expectations that as land becomes more costly, houses will be less likely to sprawl and investment in housing will take other forms. The signs of the coefficient estimates for the demographic variables (also significant) conform to the expectation that households in the child-rearing middle years will have a relatively high demand for space when compared to young adults and, as that group moves into the mature adult age group, its demand for space will decrease.

Again, the highly significant and positive coefficient estimate for expected inflation was surprising. One possible explanation for its importance is that households view their physical holdings of housing, as measured in size, as a relatively inflation-safe form of investment.

The exogenous variables in the multiple-unit share equation (equation 10) include the change in the number of young adult households, real household income, the real building site price index, and the rental price of housing. The highly significant and positive coefficient estimate for the change in the number of young adult households conforms to the expectation that multiple-unit structures (apartments and condominiums) are more likely to be inhabited by young adults than by other age groups. The coefficient estimate for household income has the expected negative sign. To the extent that multiple-unit structures are more likely to be rental properties, the tenure choice model (to rent or to buy) applies. In that model, increases in household income increase the income tax benefit of home ownership, and renting becomes less likely (Hendershott and Shilling 1982). The positive and significant coefficient estimate for the site price index suggests that construction of multiple-unit structures is one way to build more on less land as building site prices increase.

With perfect capital and housing markets (and absenting transaction costs), rent and rental price for equivalent units should be equal on the margin. Rental price, however, tends to fluctuate more than rent so that there are variations in rental price relative to rent. The coefficient estimate for the rental price of housing is highly significant and positive, suggesting that households respond to that variation and are more likely to rent when interest rates are high or when housing prices are expected to increase relatively slowly.

Base Case and Alternative Predictions

In this section, one "base case" scenario, that simulates housing market activity for the years 1996-2050, and six alternative scenarios, intended to illustrate the relative sensitivity of the predictions to variations in the underlying assumptions, are described. In each of five alternative scenarios, the growth rate for one exogenous variable was increased by 20 percent over the base growth rate for the prediction period. The variables so modified were total real disposable income, total adult population, real construction labor price, real wood price, and real building site price. One additional scenario was constructed to explore the importance of assumptions about limits on household formation by constraining the upper limit of the age-specific headship rates. The predictions of the model for number of households by age class, the constant-dollar (1987=1.0) level of investment in housing by new construction and by improvement, and square footage of new construction by unit type for the base case and alternative scenarios are described below. Average annual growth rates for the prediction period for the exogenous variables in the base case and for the endogenous variables in all scenarios are shown in table 4. In the following discussion, all dollar values are in 1987 dollars.

The Base Case

These base case housing predictions served as the basis for the housing assumptions in the 2000 RPA timber assessment. Historical levels and model predictions for the number of households (total and by age class) are shown in figure 5; constant-dollar value of investment in housing (total and by new construction and improvement) is shown in figure 6; and square footage of new construction (total and by single- and multiple-family units) is shown in figure 7. The macroeconomic assumptions for real disposable income, consumer and producer prices, and interest rates that drove the base case housing predictions were produced by the U.S. Department of Agriculture, Economic Research Service, for use in the 2000 RPA timber assessment (see footnote 2). Growth in real disposable income was assumed to decrease from an average annual rate of 3.1 percent for the sample period (1952-95) to 2.5 percent in the first decade of the prediction period and 1.8 percent in the last decade, for an overall average annual growth rate of 1.99 percent. Consumer and producer prices were assumed to grow at average annual rates of 3.0 and 2.5 percent, respectively. Real compensation for labor was assumed to grow at an average annual rate of 1.32 percent per year.[9] The real rate of return on corporate bonds was assumed to average 4.5 percent in the first decade and 2.9 percent thereafter. The population projections

[9] The real price of construction labor was assumed to grow in the base case because it is linked in the macroeconomic model to labor productivity and per capita GNP growth This contrasts with recent trends. For the last 25 years, real carpenters wages fell by 1.1 percent per year, while per capita GNP and labor productivity increased. It is beyond the scope of this paper to explore the reasons for this disparity, but it is important to note existing uncertainty about the future relations between construction labor wages and other macroeconomic variables.

Table 4—Average annual growth rates in base case exogenous variables and in base case and alternative scenarios endogenous variables

Item	Base case exogenous variables	Growth rate for endogenous variables in base case and alternative scenarios						
		Number of households	Constant-dollar, housing investment			Square footage, new construction		
			Total	New construction	Improvement	Total	Single family	Multiple family
				Percent				
Base case		1.07	1.30	1.29	1.33	0.89	0.81	1.37
Income	1.99	1.10	1.60	1.32	1.94	0.92	0.99	0.32
Population	0.78	1.23	1.36	1.44	1.25	1.06	0.83	2.21
Labor price	1.32	1.07	1.30	1.46	1.06	1.09	0.96	1.84
Wood price	0.26	1.07	1.30	1.32	1.28	0.92	0.84	1.46
Site price	0.50	1.07	1.30	1.29	1.33	0.86	0.74	1.57
Headship	–	0.90	1.21	1.09	1.36	0.67	0.70	0.39

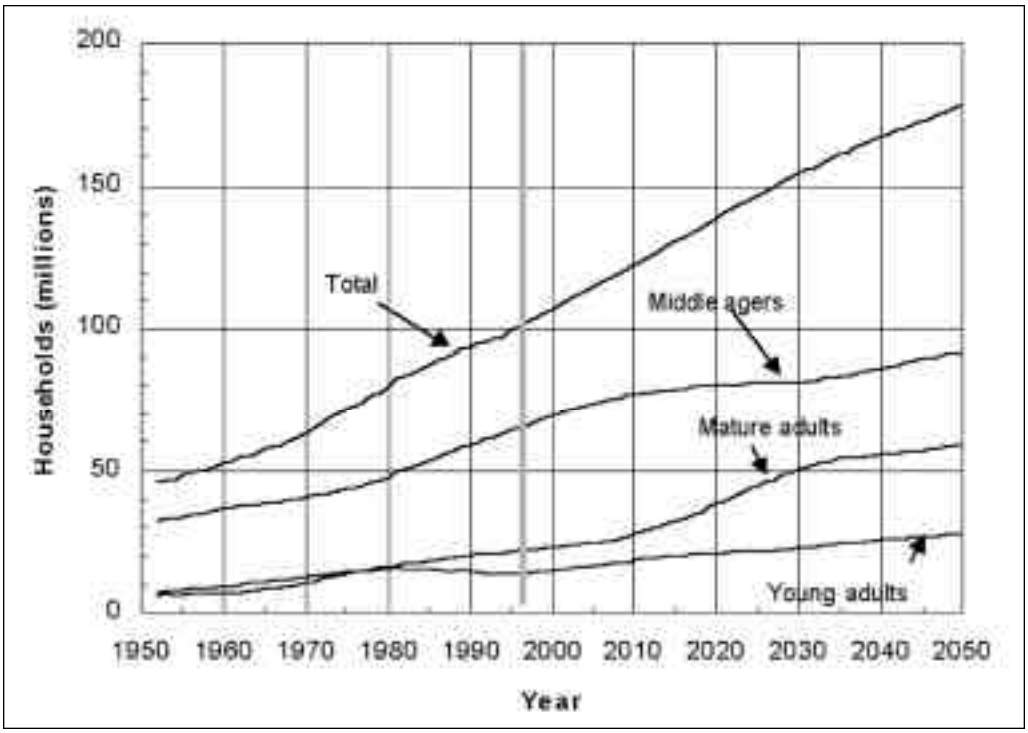

Figure 5—Base case predictions for number of households, total and by age class.

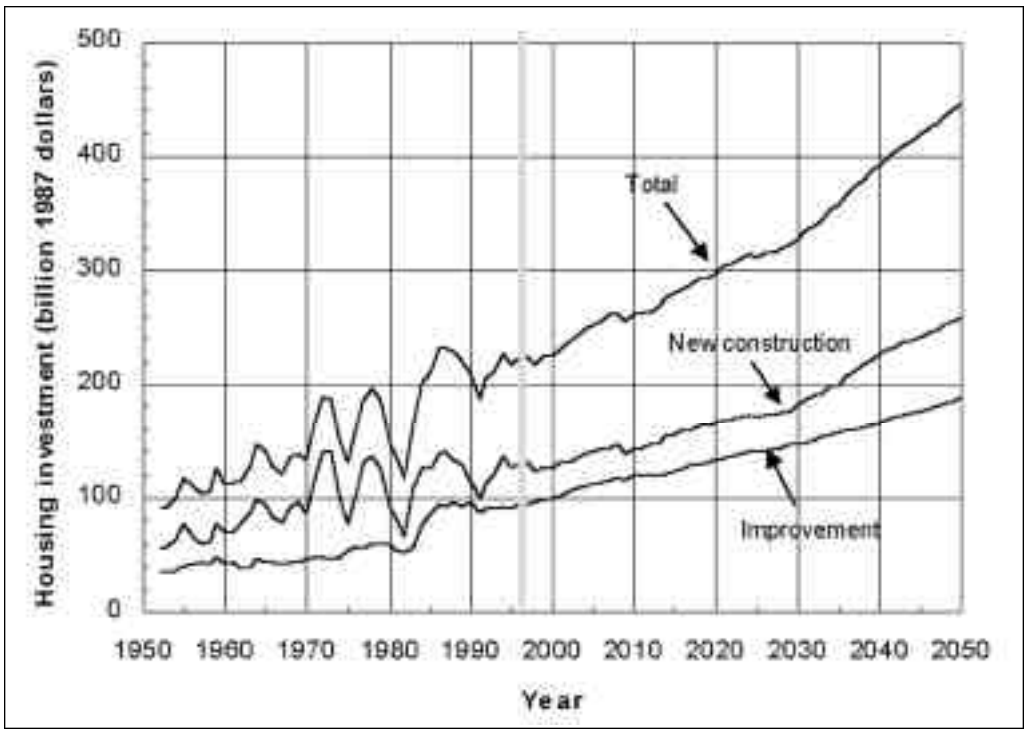

Figure 6—Base case predictions for constant-dollar housing investment, total and by new construction and improvement.

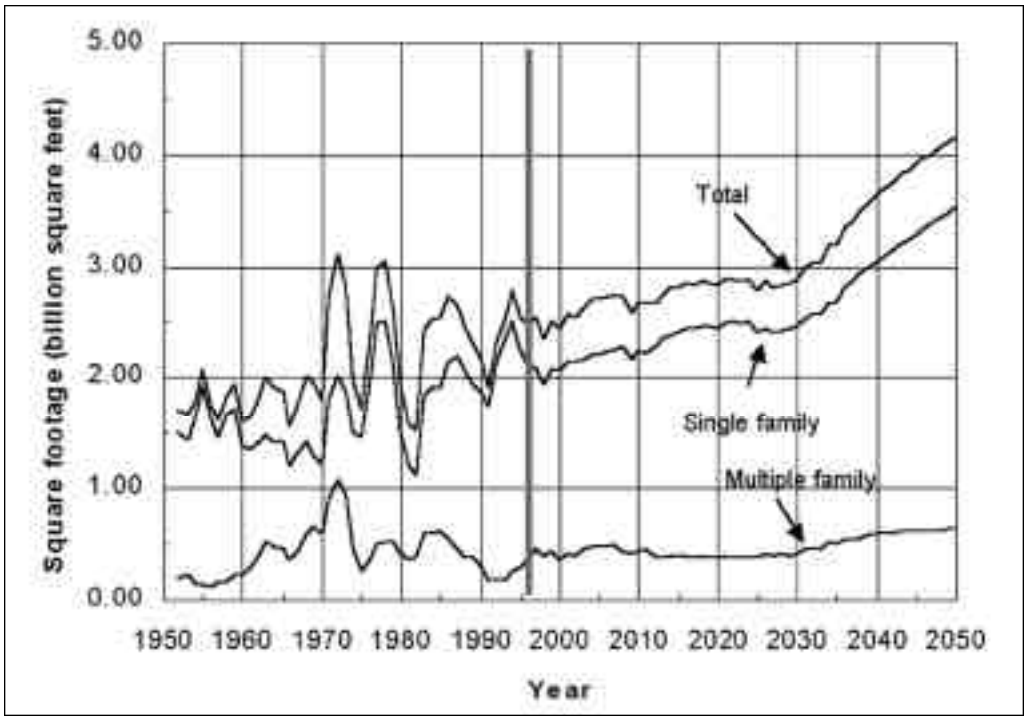

Figure 7—Base case predictions of square footage of new residential construction, total and by single- and multiple-family units.

underlying both the macroeconomic assumptions and the housing predictions are the U.S. Bureau of the Census middle series projections (Day 1996). The total adult population was assumed to grow more slowly than the 1.4-percent average annual rate of the sample period—at an average annual rate of 1.0 percent in the first decade of the prediction period and 0.6 percent in the last decade—for an overall average annual growth rate of 0.77 percent.

The building site price index was assumed to grow at an average annual rate of 0.5 percent, compared to 1.3 percent since 1959 and 0.3 percent since 1970. The wood price index was constructed by using predictions of solid wood prices and consumption levels from the last RPA timber assessment (Haynes and others 1995). The construction materials price index was linked to producer prices and prices for solid wood products. The softwood lumber use index was that predicted in the last RPA timber assessment. The marginal income and property tax rates (used in the user cost rate for homeowners) were assumed to remain constant at past mean levels.

In the base case, the number of households grows from 99 million in 1995, or about 50 percent of the total adult population, to 178 million in 2050, or about 60 percent of the total adult population (fig. 5). The average annual growth rate over the prediction period is 1.07 percent, which decreases steadily from 1.55 percent in the late 1990s to 0.66 percent in the 2040s. Historical rates average 1.78 percent over the sample period and range from a 10-year average of 2.4 percent in the 1970s to 1.3 percent

in the last decade. The number of households grows faster than the adult population for two reasons; growth in per capita income encourages household formation, and the aging of the population leads to a higher overall headship rate. The number of households grows more slowly than in the sample period because of lower growth rates for both income and population. Because the growth rate for income decreases more slowly than the growth rate in the number of households, the household income growth rate increases in the last decades of the prediction period.

Constant-dollar value of housing investment grows in the base case from $218 billion in 1995 to $446 billion in 2050 at an annual average rate of 1.30 percent (fig. 6). Again, this is lower than the historical annual growth rate of 2.04 percent because of lower growth in income and in the number of households. Predicted individual household housing investment is steady at about $2150 per household until 2030 and then increases to $2500 per household by 2050 as household income grows. This is well within the sample period range of $1400 to $2800. The improvement share remains relatively constant at about 44 percent over the prediction period.

Square footage of new construction grows from 2.55 billion square feet in 1995 to 4.16 billion square feet in 2050, at an average annual growth rate of 0.60 percent (fig. 7). It grows more slowly than constant-dollar value of new construction because of the aging population and assumed increases in real building site price. This continues the historical downward trend in square footage of new construction per constant dollar (from 28 square feet per thousand dollars in the 1950s to 20 square feet per thousand dollars in 1995, and a predicted decrease to 16 square feet per thousand dollars in the 2040s). Like constant-dollar value of new construction, square footage of new construction grows more slowly in the 2020s and, again, more rapidly in the 2030s and 2040s. This is due to more rapid growth in household income in the last two decades of the projection period as total income continues to grow while growth in the number of households slows. These fluctuations are more pronounced for square footage of new construction than for constant-dollar value of new construction from 2000 to 2030, when middle agers (those most likely to desire spacious houses for raising families) move into the ranks of the mature adults (those more likely to downsize to more manageable housing units). After 2030, the relative size of the various age groups in the population stabilizes. In the base case, single-unit structures account for a slightly decreasing share of that total as income grows and the young adult component of the population diminishes in relative importance. That trend is offset in the last two decades somewhat by increasing building site price, which encourages multiple-unit construction.

Alternative Scenarios

Five alternative scenarios involved increasing the base case growth rates for each of five exogenous variables by 20 percent, one variable at a time. This allowed comparison of the resulting changes in the model predictions across scenarios.[10] One additional scenario involved limiting the growth in headship rates to not exceed specified values for each age class: 0.5 for young adults, 0.6 for middle-agers, and

[10] Although this one-by-one approach is useful for sensitivity analysis, the results do not constitute viable alternative housing scenarios because, in fact, macroeconomic variables are interrelated and do not vary independently of one another.

Table 5—Coefficient estimates for headship-rate equations with limits (t-statistics in parentheses)

Item	Young adults, 18-29 yr	Middle agers, 30-64 yr	Mature adults, 65+ yr
Constant	-0.210 (2.94)	0.124 (2.26)	0.016 (0.16)
Rental price	-0.445 (1.95)	0.105 (0.29)	-0.034 (0.05)
Per capita income	19.266 (3.55)	8.724 (1.06)	37.068 (2.65)
Lagged headship	0.764 (12.1)	0.880 (13.1)	0.708 (7.98)
Adjusted R^2 statistic[a]	0.958	0.974	0.939
Durbin's h-statistic[b]	0.97	0.80	0.84

[a] R^2 statistic is computed for levels of headship rates, rather than transformed logits of headship rates. These give the proportion of the variation in the headship rates themselves that is explained by the regression.
[b] Durbin's h-statistic substitutes for Durbin-Watson test for 1st-order serial correlation in the residual in the presence of a lagged dependent variable. It is distributed standard normal. The null hypothesis that there is no serial correlation cannot be rejected at the 5-percent significance level if Durbin's h-statistic is below 1.96.

0.7 for mature adults. These limits were based loosely on ad hoc limits developed from assumptions about age-specific marriage behavior by Marcin (1978). There is no theoretical basis for limiting headship rates in this way, but reviewers of preliminary model predictions were concerned that the base case headship-rate predictions seemed unreasonably high: 74 percent for mature adults and 45 percent for young adults in 2050 compared to 64 percent for mature adults and 31.5 percent for young adults in 1995. Age-specific headship rates have increased in the last five decades, but continued growth might entail behavioral changes that seem unlikely from today's perspective. In light of this concern, it seemed important to assess the role of headship rates on the other predicted variables in the model. To impose the limits, the model was reestimated with upper limits placed on headship rates by modifying the logit in equation (1) to the limit values for each age class, a_j:

$$\ln\left(\frac{\underline{h_{it}}}{a_j - \underline{h_{it}}}\right) = \alpha_i \underline{R_t} + X_t^{D'} \beta_i + u_{it} \qquad (11)$$

This has the effect of constraining predicted headship rates to fall between 0 and a_i. Estimation results for the headship-rate equations are shown in table 5. The other equations in the model changed very little; estimation results are not reported here, but may be obtained from the author.

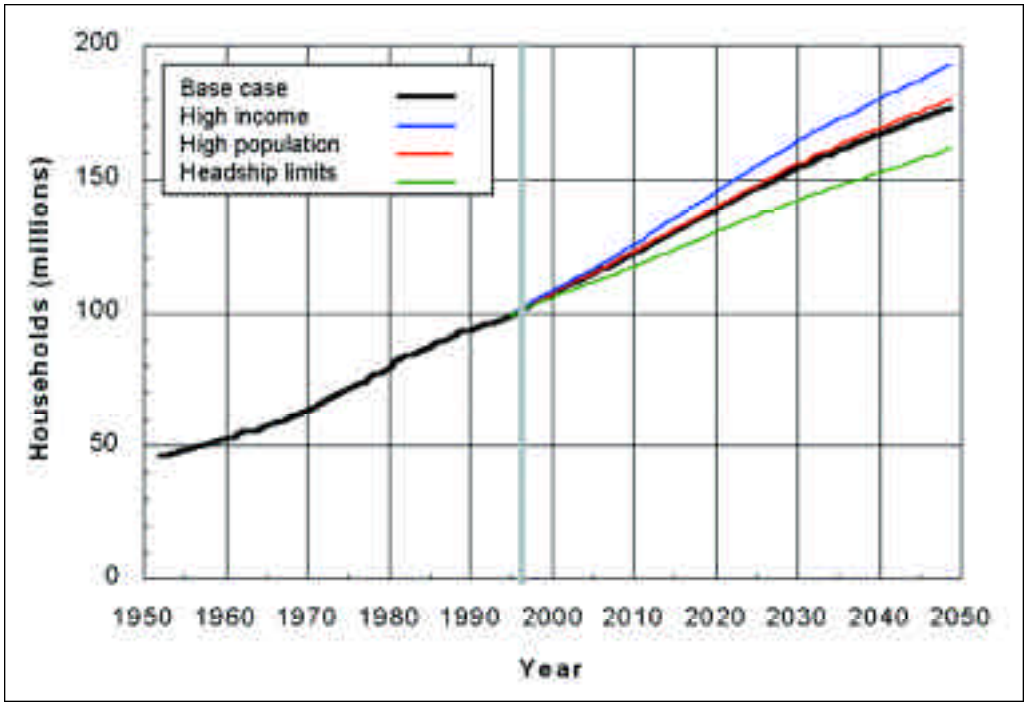

Figure 8—Alternative scenario predictions for number of households, by high income, high population, and headship-rate limits scenarios.

The average growth rates for the endogenous variables in the model are shown in table 4 for the alternative scenarios. The predictions are shown in figures 8 to 12 for each scenario for the endogenous variables that are used in the RPA timber assessment: number of households (fig. 8), improvement expenditure (figs. 9 and 10), square footage of single-family new construction, and square footage of multiple-family new construction (figs. 11 and 12).

In the high income growth scenario, income grows at an average annual rate of 2.39 percent per year. The higher income growth rate has the biggest impact on improvement expenditure and on square footage of new single-family construction. In fact, these two variables are more strongly affected in the high income growth scenario than in any other scenario. Household investment in housing responds positively to higher household income. The effect of increased housing investment on improvement expenditure is amplified by the positive effect of higher household income on the improvement share. Its effect on the quantity of new construction is offset by the increased improvement share, resulting in only a modest increase in quantity of new construction and square footage of new construction. Higher income leads, however, to a change in the allocation of square footage of new construction across unit types; square footage of single-family new construction increases substantially and square footage of multiple-family new construction decreases with higher income. The high income growth rate is well within the range of historical income growth rates, which averaged 3.1 percent per year during the sample period, and is very close to the income growth rate assumption used in the last RPA timber assessment, which averaged 2.3 percent per year. Although the base case income growth assumption is lower than that used in past RPA assessments, some analysts feel it is still too high.

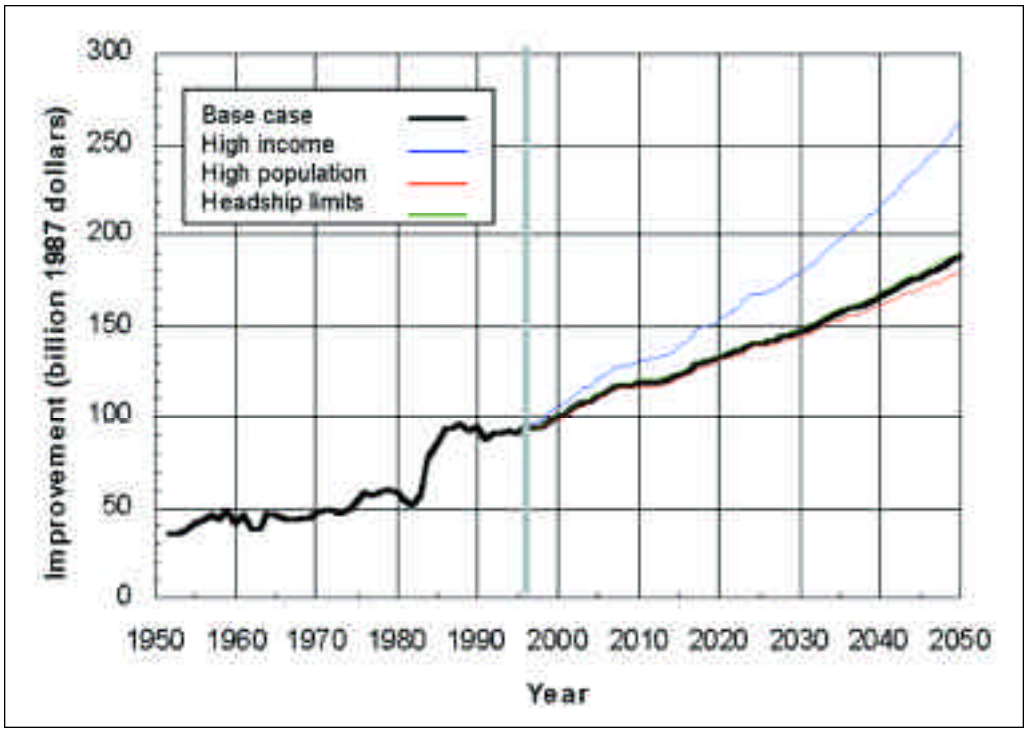

Figure 9—Alternative scenario predictions for improvement investment, by high income, high population, and headship-rate limits scenarios.

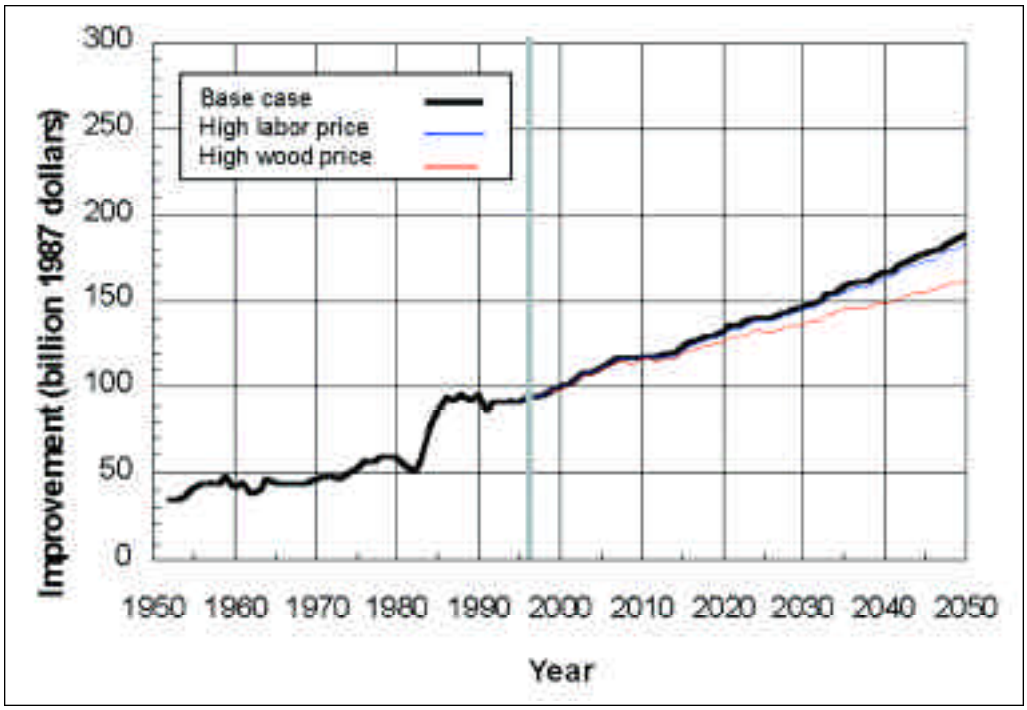

Figure 10—Alternative scenario predictions for improvement investment, by high labor price and high wood price scenarios.

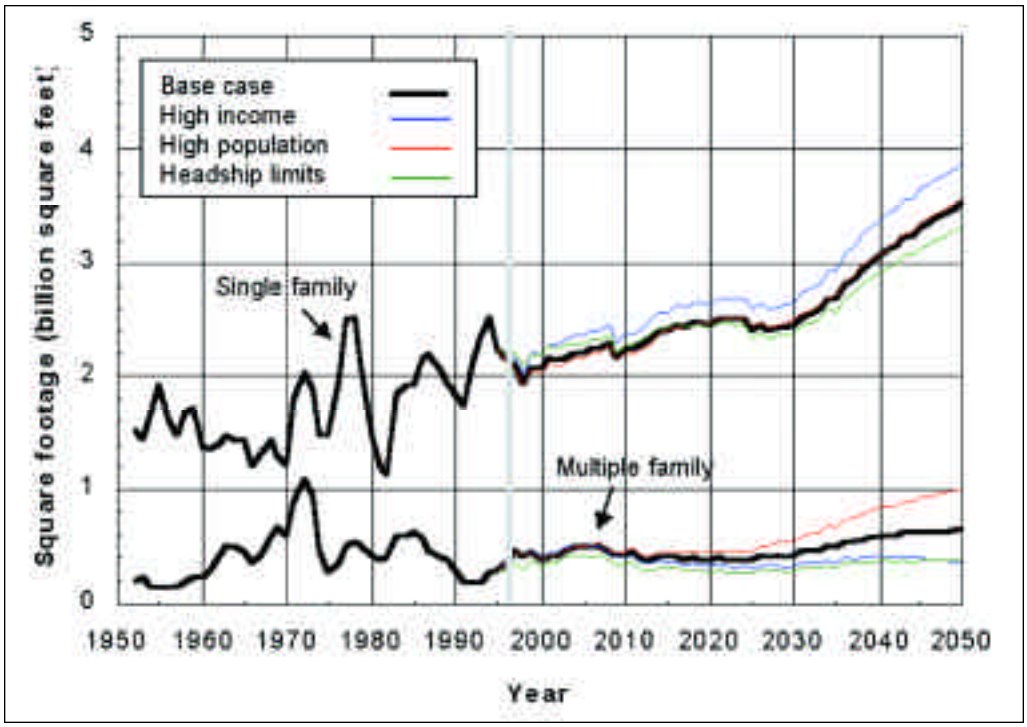

Figure 11—Alternative scenario predictions for square footage of single- and multiple-family new construction, by high income, high population, and headship-rate limits scenarios.

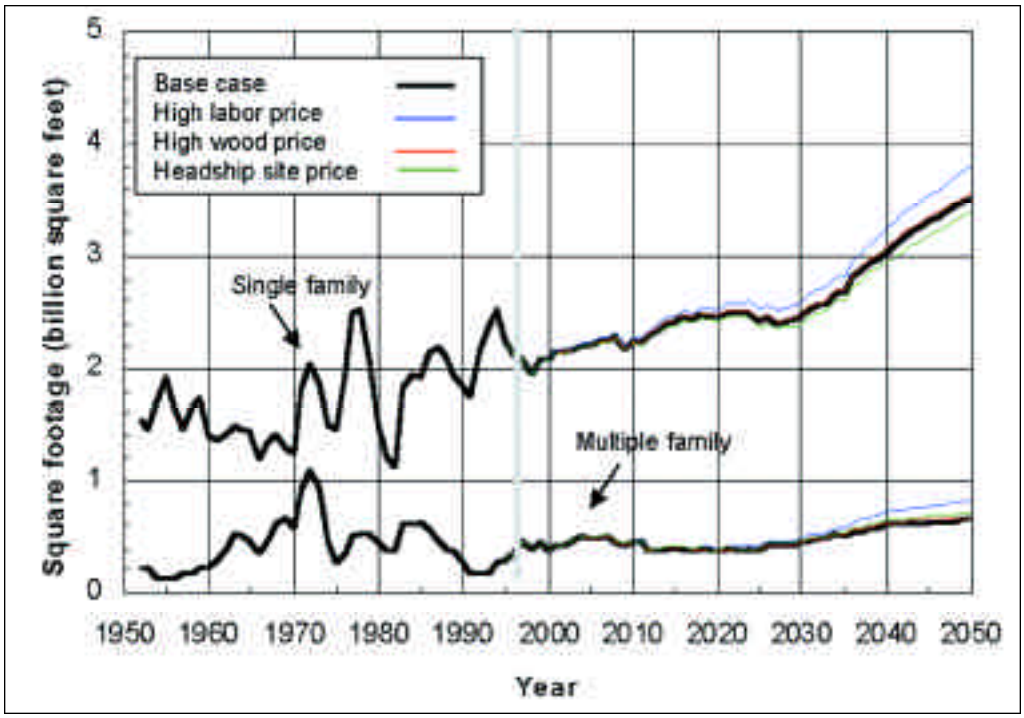

Figure 12—Alternative scenario predictions for square footage of single- and multiple-family new construction, by high labor price, high wood price, and high site price scenarios.

In the base case, per capita income is assumed to nearly double to $39,000 in 2050 from its 1995 level of $20,000. This analysis suggests that income growth assumptions are critically important to the housing assumptions and that a lower income growth assumption would lead to significantly lower predictions of housing activities important for wood use.

In the high population growth scenario, population grows at an average annual rate of 0.94 percent per year. The effects of increased population growth are substantial but different from the effects of increased income growth. The number of households increases more rapidly but the increase is less than proportional to the increase in population because household formation is discouraged by lower per capita income (the same income spread over more people). Likewise, individual household housing investment falls because household income falls. Hence, the increase in total housing investment is less than proportional to the increase in households. Lower household income leads to a shift of investment toward new construction, which grows faster than total investment as a result. This, in turn, leads to more square footage of new construction, most of which is multiple family because of lower household income and more new households in the young-adult age class. In the alternative scenario analysis, population and income are each varied independently of one another. That leads to some of the results described above; when income grows and population is constant, per capita and household incomes grow: when population grows while income is constant, per capita and household incomes fall. But population and income are not independent. The output of an economy depends on the size of the labor force, which depends on population growth. Hence, increased population growth will most likely be accompanied by increased income growth, so that the change in per capita and household incomes and the resulting impact on housing investment will be smaller than in the high population growth scenario. Even so, because the range of population growth scenarios produced by the Bureau of the Census is quite wide (from an average annual growth rate of 1.21 percent for the highest series to 0.25 percent for the lowest series), there is a correspondingly wide range of plausible future housing scenarios.

In the high labor cost scenario, real labor compensation grows at an average annual rate of 1.58 percent per year. In this model, the real price of construction labor was significant only in the improvement-share equation where its sign was negative. Hence, higher growth in the real price for construction labor fuels a decrease in improvement expenditure and an increase in square footage of new construction, evenly divided between single- and multiple-unit construction. Again, it is important to note the likely links between the exogenous variables in the model. Higher labor cost is likely to occur with higher income growth, which will offset some of the effect of higher growth in labor cost in the improvement-share equation, and the net effect on improvement expenditure and square footage of new construction will be smaller than in this scenario.

In the high wood price scenario, real wood price grows at an average rate of 0.32 percent per year. This scenario should be of interest to forest policy analysts interested in the impacts on consumers of policies constraining timber supply (e.g., the federal timber harvest reduction in the Pacific Northwest that occurred in the early 1990s).

In this model, the effect of increasing real wood prices parallels that of the increasing labor cost, but the impacts are much smaller. It appears that wood prices have not had powerful effects on housing demand in the past and, hence, are not predicted to be very important determinants of housing demand in the future.

In the high building site price scenario, real building site price grows at 0.6 percent. Site price appears only in the square footage equations. Higher site price growth dampens growth in square footage of new construction and shifts the allocation of new construction from single- to multiple-family units. The future of building site price is very uncertain. Historical growth rates in the average site price per square foot for homes qualifying for FHA loans have fluctuated from 3.4 percent increase in the 1960s to 2.1 percent decline in the 1980s. If population density continues to increase in urban areas, site prices may be driven upward. Other trends may prove to be important, too, in the evolution of building site prices, including the growing importance of the senior population and technological changes that allow for dispersed work arrangements. These trends could lead to more dispersion of new construction away from urban or suburban areas, thereby allowing access to cheaper land.

Finally, in the limits-on-headship-rate scenario, headship rates grow moderately to 67 percent for mature adults and 35 percent for young adults in 2050, which leads to lower growth in the number of households than in the base case. The reduced number of households, however, has little effect on housing investment because it means higher household income; the effect of fewer households on aggregate demand was offset by the effect of higher household income on individual demand. Growth in square footage of new construction decreases only slightly (fig. 12) because the effect of a reduction in the number of households is counteracted by increased household income leading to higher individual household housing investment demand.

Housing Starts and Average Unit Size

Although the wood products market model used in the RPA timber assessment (the timber assessment market model, Adams and Haynes 1980) uses square footage of new construction by unit type to drive derived demand for solid wood products in new residential construction, it is sometimes easier to imagine square footage of new construction as the product of housing starts and average new unit size. In fact, in past RPA timber assessments, housing starts and average new unit size were predicted separately and their product was used to drive derived demand in the wood products market model. In this study, a simple ad hoc model was constructed to disaggregate square footage of new construction into housing starts and average unit size. The purpose was merely to enable readers to envision how the predicted levels of square footage of new construction might appear in reality. The housing starts accounting model followed Maisel (1963) as did the earlier models of Marcin (1978) and Montgomery (1989):

$$starts_t = \gamma_t \, \Delta HH_t + net\ replacements \qquad (12)$$

where the total number of housing starts at time t is some proportion, γ_t, of the change in the number of households at time t, ΔHH_t, plus the net replacements. Net replacement is the number of units discarded from the housing stock plus those converted to nonresidential uses less those added to the stock through conversion from nonresidential uses. The proportion, γ_t, is the ratio of the total number of existing housing units to the number of units occupied as primary residences. It is greater than one because some units are vacant and some are used only seasonally. The share of housing starts of the multiple-family type was linked to w_t^m, the share of square footage of new multiple-family units and the change in the number of households headed by young adults.[11] Average unit size is the square footage of new construction divided by the number of housing starts for each unit type.

The prediction for square footage of new construction in the base case is consistent with a wide range of housing starts and average unit size combinations, from a few very large houses to many small houses. Figures 13 and 14 illustrate outcomes generated from equation (12) under two sets of assumptions for γ_t and net replacements.

In the "low starts" scenario, γ_t was equal to its average value since 1970 of about 1.11. Net replacements ranged from 0.24 to 0.35 percent of the housing stock per year and were lowest from 2010 to 2030, the years of most rapid growth in the number of households. In the "high starts" scenario, γ_t increased over time as higher incomes and a larger proportion in the mostly retired mature adult age group led to a higher propensity to own seasonal dwellings.[12] Net replacements were assumed to increase from 0.3 to 0.6 percent as the housing stock aged, increasing most slowly between 2010 and 2030, the years of most rapid growth in the number of households. The shape of the housing starts prediction was determined by ΔHH_t (for smoothness, a 5-year moving average was used); when starts are relatively high, average unit size is relatively low. In both scenarios, starts are within the range of historical values, while average unit size continues the upward post-World War II trend. Although the scenarios are equivalent to one another in their impact on wood consumption in the RPA timber assessment, they may have different implications for wood use in reality. It was certainly true that reviewers of the preliminary RPA housing assumptions generated by this model reacted much more vigorously when the predictions of new construction were presented as housing starts and average unit size predictions than when the same predictions were presented as square footage of new construction predictions.

Conclusion

In this study, a structural model of the U.S. housing market was developed and the parameters were estimated for generating long-term predictions of future levels of key housing market variables. This is the first time that housing assumptions for the RPA timber assessment were based on a structural model explicitly linking various housing demand and supply behaviors so that the resulting housing predictions—number of households, improvement expenditures, and square footage of new residential construction by unit type—are consistent with one another and with underlying macroeconomic assumptions.

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[11] The estimated equation for the multiple-unit housing starts share used in this illustration is (t-statistics in parentheses):
$w_t^{\text{multi starts}} = 0230(4.10) + 0.884(25.8)*w_t^m - 3.134(4.90)*\Delta HH_t^{18\text{-}29}$ $R^2 = 0.97$, $DW = 0.58$

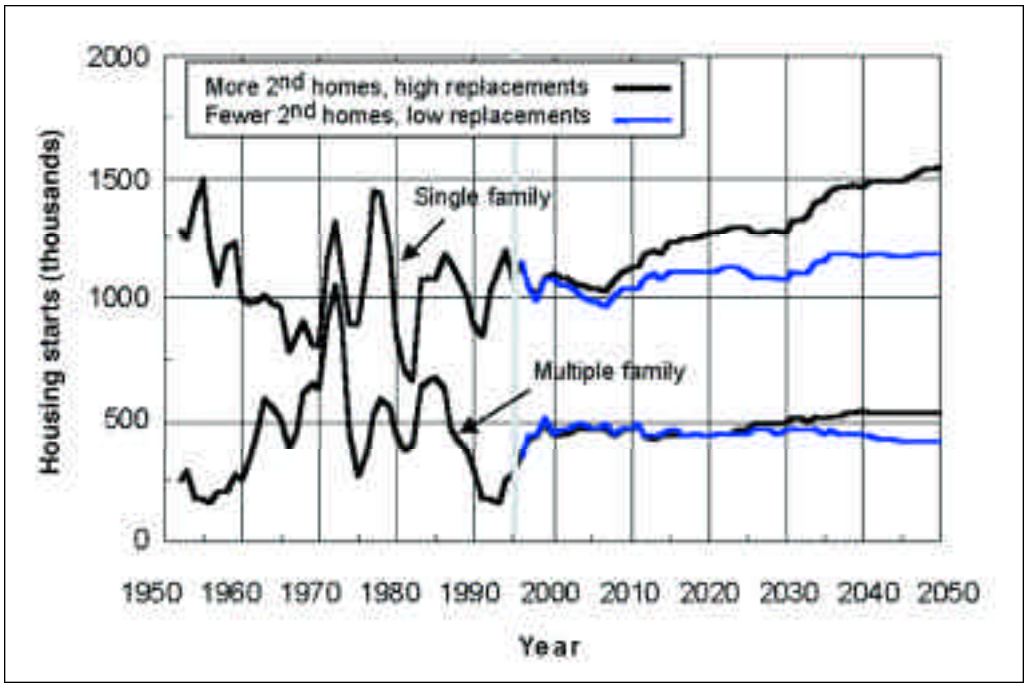

Figure 13—Housing starts.

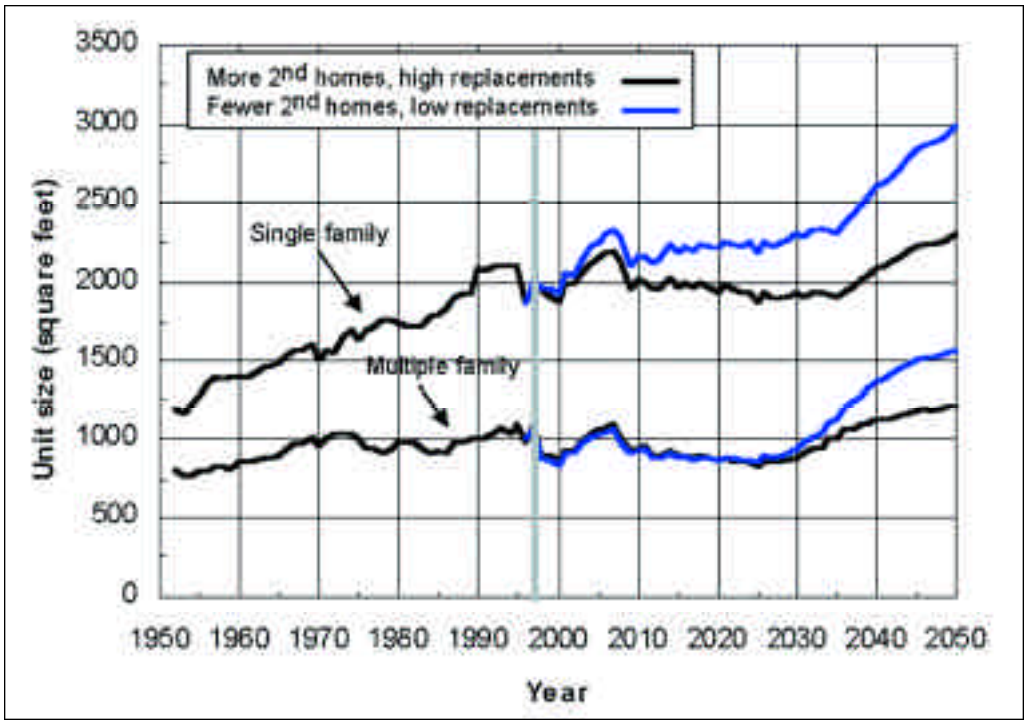

Figure 14—Average new single- and multiple-family unit size.

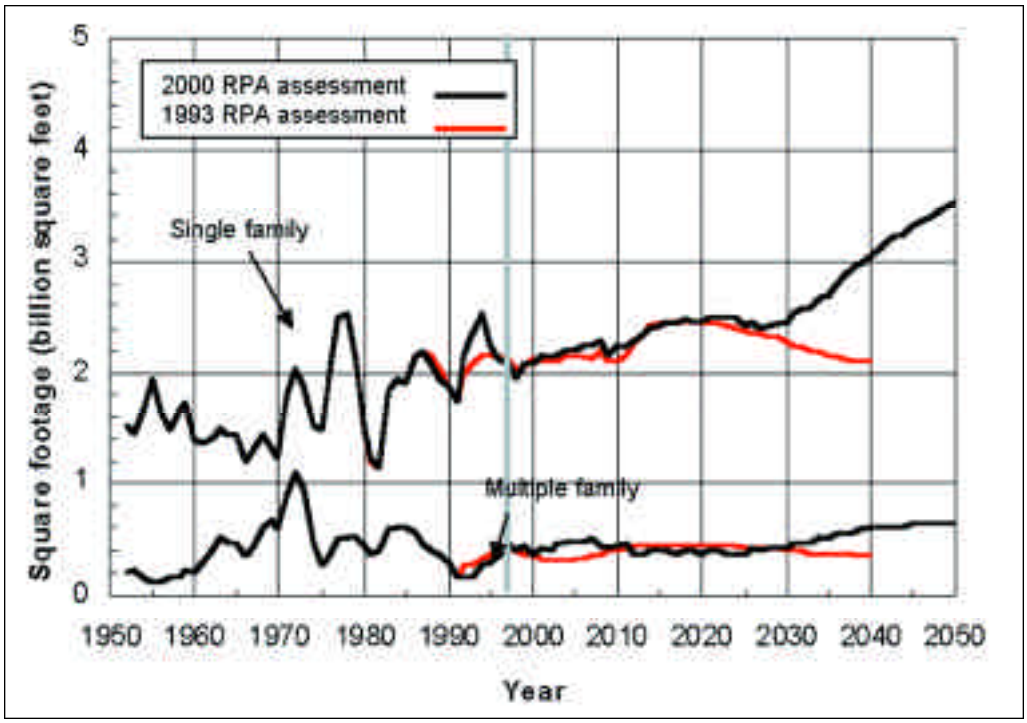

Figure 15—Base case predictions for square footage of single- and multiple-family new construction, for the 1993 RPA timber assessment and the current model.

In figure 15, assumptions for square footage of new construction used in the 1993 RPA timber assessment update (Haynes and others 1995) are compared to the predictions of this model. The predictions are remarkably similar through 2025 when they diverge. New construction is shown as declining in the 2020s and 2030s in the 1993 RPA timber assessment, but the current model predicts new construction continuing to grow because of continued income and population growth. In the 1993 RPA assumptions, average annual growth rates for the prediction periods are -0.09 percent for new construction of single-family units and -0.04 percent for multiple-family units. This compares to 0.81 percent per year for single-family units and 1.38 percent per year for multiple-family units in the current model predictions and to historical average annual growth rates of 1.42 percent per year for single-family units and -0.91 percent per year for multiple-family units from 1963 through 1995. To maintain the growth shown in the current model predictions, it is necessary that people

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[12] For this scenario, the ratio of total number of housing units occupied during some portion of the year to the number of housing units occupied year-round, γ_t, was linked in a simple univariate regression to the proportion of the population in the mature adult age group (t-statistics in parentheses):
γ_t = 0934(52.6) + 0.561(5.07) *proportion of population in mature adult age group, R^2=0.62, *DW*=1.8

respond to increased income by either continuing to demand larger and larger homes or choosing to hold multiple homes. Both behaviors are observed in today's retirement communities. As retirees enjoy greater longevity and health, many are choosing to maintain larger homes and to migrate between homes.

The 1993 predictions were derived from a household formation model that used the Maisel approach (Montgomery 1989). Headship rates using Marcin's (1978) upper bounds were limited. Housing starts for single-family units were predicted to decline over most of the prediction period and to fall well below historical levels; multiple-family housing starts were predicted to hold steady at slightly lower than historical levels. This was combined with moderate assumptions about growth in average unit size; single family units were assumed to increase to 2,275 square feet and multiple family units to 1,410 square feet by 2040. The resulting decline in new residential construction after 2020 contrasts sharply with the healthy growth assumed to occur in the overall economy during that period; income was assumed to grow at an average rate of 2.4 percent per year during the 2020s and 2030s. Such a discrepancy between growth in the housing sector and in the overall economy is not consistent with the recent past, when the housing sector and overall economy have been closely synchronized. That does not mean that it could not occur, only that there is no evidence based on past behavior to indicate that such an outcome is likely.

One strength of econometrically estimated structural market models is that they provide an internally consistent summary of past behavior. Any prediction or alternative scenario that the model produces will have the same internal consistency imposed. Hence, these models are useful for performing "what if" scenario analyzes (e.g., What if income does not grow? What if immigration rules change? and so on). The main weakness of these models is that they do not describe the future; they describe the past. The predictions of the future depend on the implicit assumption that people will behave in the future as they have in the past. It cannot be known whether that will be true. Keeping that qualification in mind, this structural model of the housing sector can be productively applied in several ways:

- To identify variables likely to be important in the evolution of housing markets and, hence, wood demand. This analysis identified a few variables that seemed to be important (income and labor cost) and a few that seemed to be unimportant (wood cost and, for some variables, the number of households).

  This is useful because model predictions depend on assumptions about future trends in exogenous variables that may be highly uncertain. For example, building site price appears to be important for wood use because it affects square footage per dollar invested in new construction and the allocation of new construction between single- and multiple-family units. Long-term predictions about land scarcity and prices are largely speculative, however. There may be some information in urban growth models, but to apply that directly, either regionally or nationally, may not be appropriate. A few decades ago many analysts predicted increasingly dense populations in urban centers with dramatically increasing land values; today, one might speculate that the opposite could occur as technology-based employment and an increasingly mobile retired population contribute to a more geographically dispersed population in areas where land values are low.

This is also important because it gives policy analysts some idea about which policy scenarios likely will matter. For example, there has been interest in recent years in the potential effect of increasing wood scarcity on housing demand. But the results of this study suggest that it may not have much effect. Housing demand does not seem to be particularly price responsive, although wood price does appear to play a role in the allocation of housing investment between new construction and improvement.

- To help analysts understand the role of the underlying structural assumptions that are necessarily a part of any econometric model. These include the assumption that preferences (e.g., for space and privacy in housing), household technologies (e.g., for household production of housing services), and the policy environment (e.g., in favor of the "American dream" of home ownership) will, in the future, remain unchanged from the past. Reasonable alternative scenarios for those structural assumptions might be considered and incorporated into a structural model. For example, if the marginal utility of additional housing diminishes rapidly for most people, so they reach housing saturation point, they might allocate less of their additional income to housing in a wealthy future than they have in the past.

- To identify policies that might encourage behaviors that lead to desired futures. This model has no normative interpretation. That is, it does not imply anything about the desirability of the predicted futures. It only suggests what the future might be under a given set of behavioral assumptions. But society may have preference for one outcome over another; e.g., people concerned about biodiversity loss from alteration of habitat in forested landscapes might be interested in policies that reduce wood demand arising from new residential construction. This model suggests that such a future is unlikely to occur spontaneously under reasonable assumptions about future income and population growth and that policy intervention would be required to increase its likelihood.

Several opportunities exist for improving housing sector market analysis:

- This analysis relied on traditional econometric analysis of time series data. Even though it has long been understood that many of the macroeconomic data series used in market modeling do not appear to have stationary means and variances, thereby violating the requirements of the classical linear regression model, it is only in the 1990s that methodologies for testing nonstationarity and analyzing long-term relation with nonstationary data have begun to be developed and used. Studies that explore the importance of stationarity in housing models include Blackley (1999) and Montgomery (forthcoming). Models of housing markets that use the techniques of cointegration analysis to identify long-term relations are beginning to appear in the literature, but these models are seriously constrained in the number of variables included (e.g., Kenny 1999). Because the purpose of this model is long-term predictions, it would be useful to critically examine it for the effects of nonstationarity (e.g., Montgomery, [in press]) and, perhaps, to apply the techniques of cointegration analysis if the set of relevant variables can be reduced to a manageable size.

- Model predictions depend on uncertain parameter estimates and uncertain predictions of exogenous variables. Methods for exploring the importance of un-certainty and defining confidence intervals about model predictions include bootstrapping and constructing response surfaces for the various exogenous variables. Such an analysis might help policymakers understand the nature and magnitude of the uncertainty in model predictions.

- In this model, an array of housing decisions are related to one another: household formation, housing investment, mode of investment, new construction supply, and square footage as an attribute of new construction. Other possibilities include improvement in the modeling of technological change in housing construction and improvement, tenure choice (rental versus ownership) and the relation between that and demand for single-family and multiple-family construction, occupancy rates for the existing housing stock, aging and replacement of existing housing, second home ownership, and mobile home markets. These are just a few of the possible extensions of this model that would increase its usefulness for predicting derived demand for wood in residential construction.

Because housing investment so strongly influences demand in solid wood products markets, it should be of critical interest to forest policy analysis and planners. This model incorporated several advances in structural modeling of the housing sector and it will provide a basis for further analysis to improve our understanding of fundamental housing market relations.

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Metric Equivalents

1 square foot = 0.0929 square meter
1 billion board feet = 5.66 million cubic meters

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Appendix: Historical Data

The data are annual series from 1952 through 1995. All price indexes are 1987=1.0 and all prices and income are deflated by the Consumer Price Index (CPI) for all goods excluding shelter (1987=1.0). All rates are given in decimal form unless indicated as a percentage.

Endogenous Variables

Number of households by age of head: U.S. Bureau of the Census, Current Population Reports P-20, "Household and Family Characteristics." *Investment in residential housing:* U.S. Bureau of the Census, Current Construction Reports C-30, "Value of New Construction Put in Place," and C-50, "Expenditure for Residential Upkeep and Improvement." *Price of new construction:* for 1963-95; U.S. Bureau of the Census "Single Family Houses Under Construction Price Deflator:" for 1952-62; Revised Deflator for New Construction, U.S. Bureau of Economic Analysis, "Survey of Current Business," Oct. 1974. *Housing starts and average new housing unit size:* U.S. Bureau of the Census, C-20, "Housing Starts", and C-25, "Characteristics of New Housing."

Exogenous Variables

Resident population by age, disposable personal income, cost of capital for builders (Moody's AAA corporate bond rate), construction materials price, 10-year U.S. Treasury bond rate: U.S. Bureau of the Census, "Statistical Abstract of the United States" and "Historical Statistics, Colonial times to 1970," and U.S. Bureau of Economic Analysis, "Current Business Statistics." *Marginal income tax rate:* Internal Revenue Service, "Statistics of Income" following Barro and Sahasakul (1983). *User cost of capital for homeowners:* computed as [(nominal interest rate + property tax rate) * (1 - marginal income tax rate) - expected inflation + depreciation rate - expected real asset price appreciation] where the property tax rate is constant at 1 percent, the depreciation rate is constant at 2 percent, models for expected inflation and expected new construction price appreciation are described in text, and the nominal interest rate is the 10-year U.S. Treasury bond rate. *Softwood lumber use index:* for 1952-83; U.S. Department of Agriculture, Forest Service, unpublished data on file at Forest Products Laboratory, Madison, Wisconsin, for 1967-95; Western Wood Products Association, "Statistical Yearbook of the Western Lumber Industry," Portland, OR. *Wood products price indexes:* U.S. Bureau of Labor Statistics "Producer Price Index" and Random Lengths Inc. "Random Lengths Yearbook," Eugene OR. *Wood products consumption:* Haynes and others (1995). *Site price index:* U.S. Department of Housing and Urban Development, Federal Housing Administration, "FHA Homes" and "Characteristics of FHA Single Family Mortgages." *Housing stock–number of vacant, seasonal, and year-round units:* U.S. Department of Housing and Urban Development, "U.S. Housing Market Conditions." *Carpenters' wages:* U.S. Bureau of Labor Statistics, "Employment and Earnings."

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