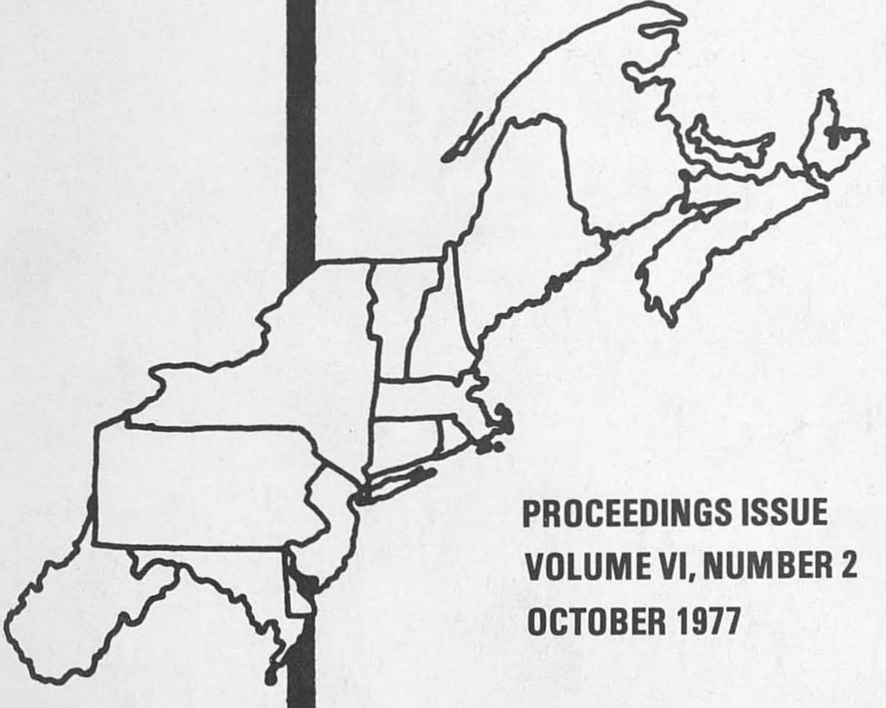
JOURNAL OF THE

Northeastern Agricultural Economics Council



PROCEEDINGS ISSUE
VOLUME VI, NUMBER 2
OCTOBER 1977

COMPARISON OF DENSITY AND AREA MODELS FOR ANTICIPATING URBAN GROWTH IN EASTERN MASSACHUSETTS*

Clayton W. Ogg and John W. Green
Agricultural Economists
United States Department of Agriculture
Economic Research Service

Introduction

Growth in residential land use is a relatively visible and permanent change taking place in communities across Massachusetts and in many parts of New England. These changes have generated considerable public concern and have been the subject of professional study by several disciplines.

Projection of urban growth is one tool enabling people in Massachusetts to anticipate future changes within regions, and particularly, to consider whether action should be taken to alter the direction or the speed of land conversion. For some purposes, it has been useful to project change in terms of population or housing density, using economic indicators and accessibility information to anticipate where people will locate. Yet changes in population are not always a good measure of how much land will be taken for residential uses. For describing urban growth pressures on farm land and rural landscapes, projection of land conversion to residential uses is a more appropriate forecasting technique. Unfortunately, there has been insufficient data to provide direct residential area projections for rural or urban fringe environments, thus prompting use of housing unit density projections.

Massachusetts is therefore quite unique in having a source of data well suited for residential area projections. This is provided by a massive photo interpretive project by William P. MacConnell and others at the University of Massachusetts [6]. More than 100 land use categories were recorded and mapped for Massachusetts towns for 1952 and 1972, including forty forest land categories and an extensive breakdown of agricultural, urban, and wetland types.1/

---

*Data used in this study was developed jointly for the Southeastern New England Water Resources Study and the Massachusetts Water Resources Study.

1/

While MacConnell's data provides an immediate opportunity to apply land use variables in a forecasting model, remote sensing techniques of the U.S. Geological Survey [9] and others, will soon make similar land use data available for much of the country.

A residential area forecasting model is now available for 166 towns which make up the heavily populated eastern portion of Massachusetts. The model is based upon residential density forecasting regressions similar to those described in the literature [3, 5, 7, 10]. This paper will show how the residential area model presented here builds upon elementary location theories.[2/] A principal objective is to indicate advantages of projections of growth in residential land area for measuring growth pressures on the environment. Some of these advantages are obvious from the respective model constructions. They become more evident from model comparisons and from comparing mapped forecasts of proportional changes in residential housing density per acre versus similar long term projections of changes in each town's residential surface area.

Factors Affecting Growth in Density and in Residential Acres

The main variables which have been associated with growth in housing density are expected to also be important in explaining growth in residential land area. It was therefore hypothesized that accessibility to places of employment and availability of land suitable for residential development would be among the most important in explaining residential land conversion [3, 7, 10].

The land use model also makes some substantial adjustments which distinguish its objectives from those of the residential density model. The need to account for variation in lot size for residential area projections requires additional variables concerning the type of land that is available for development and the kind of development that has already taken place.[3/] Also, since lot size is expected to be positively correlated with the value of housing units in each community, a unit value variable is included in the area forecasting model. These adjustments are intended to extend the models for explaining residential density growth to also account for variation in rates of land consumption as new houses are built.

Although land use and housing densities are influenced by some of

---

2/ "Elementary" density models mentioned here can be contrasted with large urban models which appear to be based upon more complete theories about urban growth processes [10]. Ingram provides the most satisfying of the big models in its representation of economic processes, but like the other large models, it is expensive and makes such demands on the available data that the potential solutions may never be sufficiently detailed [4].

3/ Variables for alternative land availabilities are intended to represent opportunity costs of undeveloped lands. Those which specify past land developments represent the main effects of previous capital investments. For making twenty year projections, these variables are considered a useful representation of the economic forces that are changing the landscape.

the same independent variables, even these independent variables are expected to have very different roles in explaining changes in the respective dependent variables. Large differences between the two models and in the mapped projections would emphasize the advantages of area projections, since density projection is obviously the less effective indicator of pressure on farm land and open space.4/

Variable Construction for the Forecasting Models

All of the forecasting regressions displayed here contain land use variables (cropland, forest, etc.) representing attractiveness of the location for development and one variable indicating accessibility to centers of employment. In addition, average dwelling unit values and industrial, divided highway, and commercial shares of town areas are included in the residential land use equations to represent effects of existing development on the desirability of undeveloped land. These independent variables appear in the alternative forecasting equations presented in Table 1.

All of the land use variables in Table 1 are aggregations of 1952 data developed by MacConnell [6] for 166 towns in Eastern Massachusetts. Dependent variables are land use changes between 1952 and 1972. Definitions of the land use variables are as follows:

Forest land -- All forest land categories divided by the total surface area of the town. This variable is an aggregation of forty forest land categories mapped and tabulated by the MacConnell study.

Public open land -- Proportion of public parks, lakes, and beaches.

Cropland -- Proportion of land used for crops and orchards. (Does not include cranberry bogs.)

Other agricultural land -- Proportion of land in pasture and all land being used for agricultural production, except cropland. (Idle land in farms is, of course, not included.)

Residential land -- Proportion of land in residential lots, from very closely spaced lots, to estates of over three acres. Included are access roads, parking facilities, and land associated with the development.

4/ For that matter, any land use model can only partially represent environmental amenities. Even our surface area projections ignor location of development within towns, and thus, may fail to represent some of the most glaring growth problems.

Table 1
Regression Coefficients for Five Alternative Specifications
of Residential Area and Residential Density Forecasting Models[a/]

Independent Variables \ Regression # / Dependent Variables:	Residential Area Models 1 Residential Share	2 Residential Share	3 Residential Share	Density Models 4 Log Density	5 Log Density
Cropland	-0.063	0.069		0.007	
	(0.185)[b/]	(0.209)		(0.005)	
Other agricultural land	0.456	0.403		-3.409	
	(0.150)	(0.166)		(1.081)	
Forest land	0.223	0.213		-3.423	
	(0.050)	(0.050)		(0.345)	
Public and open land	0.147	0.152		1.781	
	(0.059)	(0.065)		(0.435)	
Undeveloped land			0.224		-4.075
			(0.044)		(0.305)
Employment accessibility	0.020	0.028	0.027	0.348	0.260
	(0.010)	(0.011)	(0.010)	(0.079)	(0.067)
Housing units average value	0.002	0.002		0.003	
	(0.000)	(0.000)		(0.003)	
Industrial	1.363				
	(0.235)				
Divided highway	8.390				
	(1.740)				
Commercial	-1.404				
	(0.264)				
Intercept	-0.349	-0.406	-0.366	-2.922	-0.657
	(0.106)	(0.122)	(0.112)	(0.925)	(0.760)

Table 1 (Cont'd)
Regression Coefficients for Five Alternative Specifications
of Residential Area and Residential Density Forecasting Models[a/]

Independent Variables \ Regression # Dependent Variables:	Residential Area Models			Density Models	
	1	2	3	4	5
	Residential Share	Residential Share	Residential Share	Log Density	Log Density
Coef. of Determination (R^2)	0.441	0.243	0.154	0.707	0.668

a/ According to Carl Swerdloff and Joseph Stowers, equations such as ours, using residential share of developable land as the dependent variable are superior to those using either residential acres or the log of residential acres. Where the variables are expressed in acres they argue that error estimates may be biased by possible correlation with town size, and the log form tends to bias coefficients "to provide good fits to small values and poor fits to larger values of the dependent variable" [7].

b/ Standard errors are given in parentheses.

Residential share -- Ratio of residential land to developable land. Developable land is defined to include forests, residential land, agricultural lands, abandoned and idle land, shallow and shrub swamp, and seasonally flooded areas. Excluded from the denominator are lands considered physically incapable of supporting housing except by the most severe alteration of the environment.

Industrial, divided highway, and commercial -- Proportion of town area in the three respective uses.

Much of the data used in this study was obtained from files constructed from the Southeastern New England Water and Related Land Resources Study, which was a Level B study sponsored by the New England River Basin Commission.5/ This study provided the accessibility variable, which is a key variable influencing location decisions. The attraction of employment destinations and the cost of driving to each destination are weighted in this variable through the following equation:

$$A_i = \sum_{j=1}^{n} a_j \cdot f(t_{ij})$$

where A_i = accessibility for origin zone i

a_j = employment at place of work for the 166 destination zones j

$f(t_{ij})$ = $e^{-\beta t}$, where the selected β value is .15 and t is the minimum travel time in hours

Activity levels, represented as town employment by place of work, were estimated from U.S. Department of Commerce data and State Division of Employment Security data, with the latter source providing much of the agriculture and forestry data [1]. The value of β which represents alternative resistances to travel, was set at .15 based on comparison of regression equation fits using alternative values.

The remaining variables were obtained from the Census and do not require definition. Census data were for 1950 and 1970; all of the land use data were only available for 1952 and 1972, so there is a slight discrepancy. However, this is a very minor problem for a model of this type.

5/ Using the EMPIRIC model [1], a highway network was constructed for Massachusetts. Fortunately many state transportation departments now have such a network. (For further discussion of accessibility variable construction see [3, 5, and 10]).

Comparison of the Residential Land Use Model and Density Model

Although the residential area model in equation 1 of Table 1 uses some of the same variables that are taken from the density model in equation 4 of the same table, it is already evident that they emphasize very different growth concerns. Yet certain comparisons of individual parameters suggest themselves, and equation 2 was included for the purpose of making these comparisons. Notice that variables for cropland, other agricultural land, and forest land do not even share the same sign between the two models.

Also, several variables that are important in explaining consumption of residential acres are not important in accounting for growth pressures as measured by growth in housing density. In particular, the unit value variable and the breakdown of developable land into four variables are relatively unimportant in the residential density model (equation 4) as compared to the model explaining residential land consumption in equation 2. Dropping the nonsignificant unit value variable and aggregating the land variables (equation 4 vs equation 5) results in only a slight decrease in R-square for the density model, from 0.707 to 0.668. When land use variables in equation 2 are similarly aggregated for the residential area model, and when the now highly significant unit value variable is again dropped, the R-square falls to only 0.154 (equation 3). Changes in residential acres are thus closely associated with certain types of land uses and land availabilities, while density changes apparently do not share these relationships, at least not with the variables selected here. These differences between the density and residential area models have important implications for anticipating and explaining growth pressures.

The land use model is also distinguished by use of variables representing past land use decisions which are associated, in very predictable ways, with residential area growth. In equation 1 the proportion of town area in commercial land uses is negatively correlated with residential land conversion, while variables representing industrial and divided highway shares and housing unit values are positively correlated with growth. For Eastern Massachusetts, these four variables display coefficients possessing very high levels of statistical significance. (Unlike variables for available land, these three do not appear to have a predictable relationship with housing density and are not included in the density model.)

That density and area forecasting models weight the independent variables differently within each model is very evident from a brief look at standardized beta coefficients for equations presented in Table 2. Their standardized beta values indicate the coefficient assigned to each variable, after its observations have been standardized for purposes of

Table 2

Standardized Beta Coefficients for a Residential Area Forecasting Model and the Density Forecasting Model

	Residential Area Model	Residential Density Model
Undeveloped land share	0.42	-0.71
Accessibility to employment	0.18	0.19
Unit Value	0.28	0.08
Intercept	0.00	0.00

comparison, by expressing each observation in standard deviation units.[6/]

As in Table 1, the negative standardized coefficient (-0.71) for undeveloped land in the density model contrasts sharply with the large positive figure in the area model. The negative coefficient in the density model apparently indicates housing units are much more likely to be built in locations that are already relatively developed, rather than on undeveloped lands. The positive coefficient for undeveloped land in the area model may result from units in the less developed areas occupying larger lots, thus causing residential land use to grow rapidly in those areas. The negative impacts of undeveloped land variables on residential construction is apparently outweighed in the area forecasting model by more extravagant use of land per housing unit.

The other important difference between the two equations in Table 2 results from the weight assigned to the housing unit value variable: the

---

6/ Standardized beta coefficients are estimated from data standardized to the following form:

$$x_{1i} = \frac{X_{1i} - \overline{X}_1}{S_1}$$

where x_{1i} is the standardized observation i for variable X_1,

X_{1i} is the original data for variable X_1,

$\overline{X}_1$ is the mean,

and S_1 is the standard error of $\overline{X}_1$.

density model gives unit value a much smaller weight relative to its other variables. The large relative weight for unit value within the area model is consistent with the hypothesis that valuable homes are associated with large lots.

One important similarity between the two models is the large weight assigned to employment accessibility. This will result in some substantial areas of agreement when the two models are used to measure development pressures.

Comparison of Mapped Results for Density and Area Models

Mapped projections of proportional changes in residential densities and residential area can be compared in Figure 1 and Figure 2, respectively. (In each case the class interval boundaries are 1972-1992 projected changes dividedby the 1972 figures.) The two maps primarily demonstrate effects of the different growth parameters which distinguish the two models. For area projections, undeveloped and remote areas experience the most dramatic changes, while density growth is distributed among higher frequency classes for many areas that are already highly developed. Area projections thus emphasize the growth pressures on lands that are relatively open in 1972, at the beginning of the projection period.

There is, however, some agreement between the two maps as to the main directions of growth, in spite of the different emphasis as to growth rates for certain areas. In particular, the main fingers of growth extending south and west of Boston move through the same towns, in both maps.

Growth measures are therefore comparable in recording the effects of accessibility on urban growth. Both maps show lines of growth along freeway routes, such as those south of Boston to Cape Cod, Providence, Fall River, and New Bedford. However, the bands of growth are more spread out in Figure 2, perhaps indicating again the impact of varying desirability of land classification on land conversion, versus the greater emphasis on accessibility in the density model. The same tendency is apparent in comparing the two growth measures on the freeway and highway route from Boston up to Lawrence, with the area model showing a wider spreading of growth.

There are also marked differences between the two maps for certain Cape towns. Although these differences are more difficult to interpret, the available public land variable and attractiveness variable may be differentiating the two models in their projections for this unique area.

In summary, if it were necessary to rely on density projections alone, some of the main directions of residential area growth in Eastern Massachusetts could still be delineated. However, the density model, which does not take variables affecting lot size into account, would give insufficient warning of the high relative magnitude

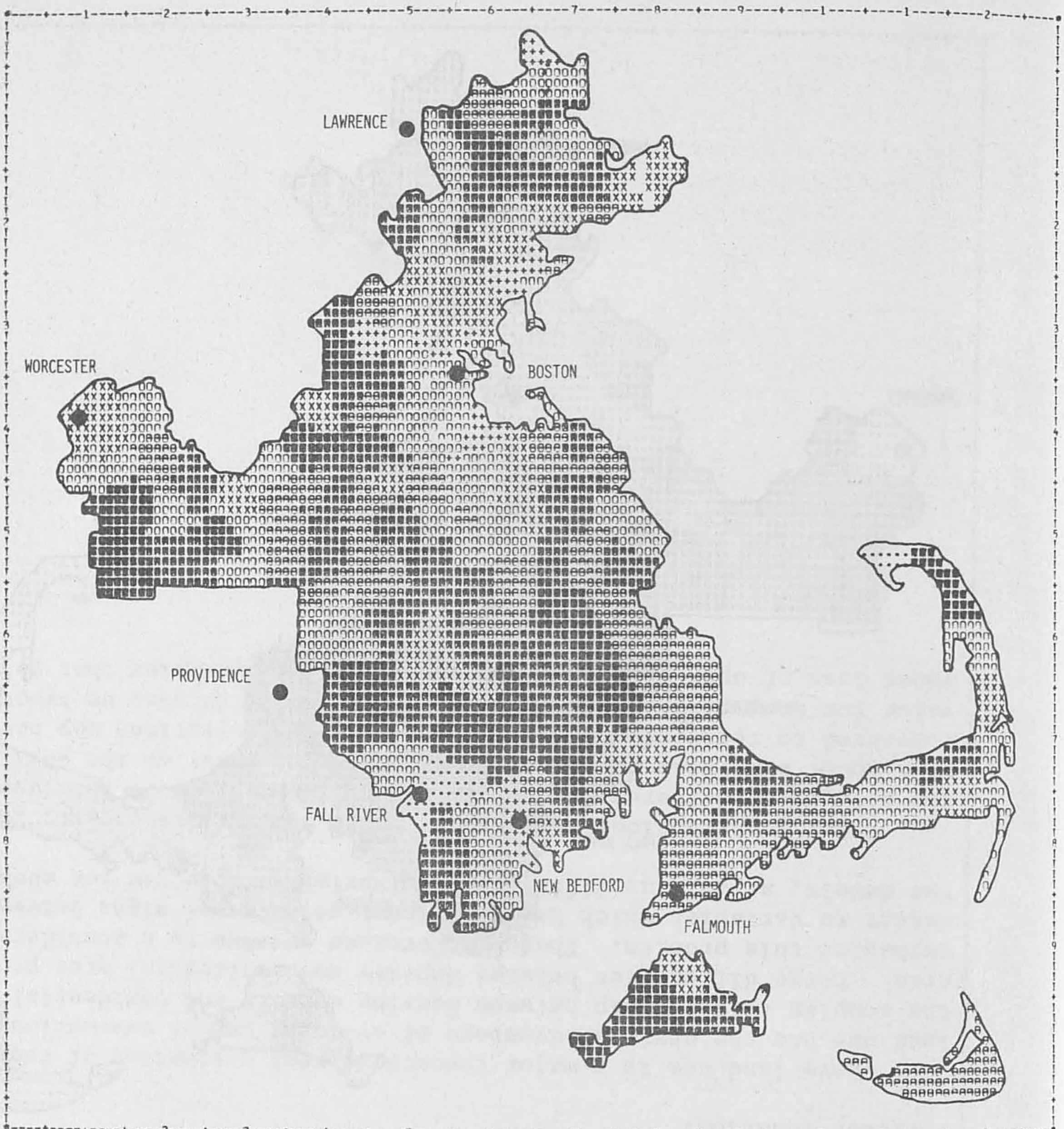


FIGURE 2: PROJECTION OF PROPORTIONAL CHANGES IN RESIDENTIAL DENSITY, 1972-1993

LEVEL	1	2	3	4	5	6	7	
SYMBOL	.	+	X	O	@	▒	■	
FREQUENCY (NO. OF TOWNS)	2	8	26	46	29	36	19	
CLASS INTERVAL	0.12	0.15	0.30	0.50	0.75	1.00	1.50	MINIMUM
	0.15	0.30	0.50	0.75	1.00	1.50	3.67	MAXIMUM

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
("MAXIMUM" INCLUDED IN HIGHEST LEVEL ONLY)

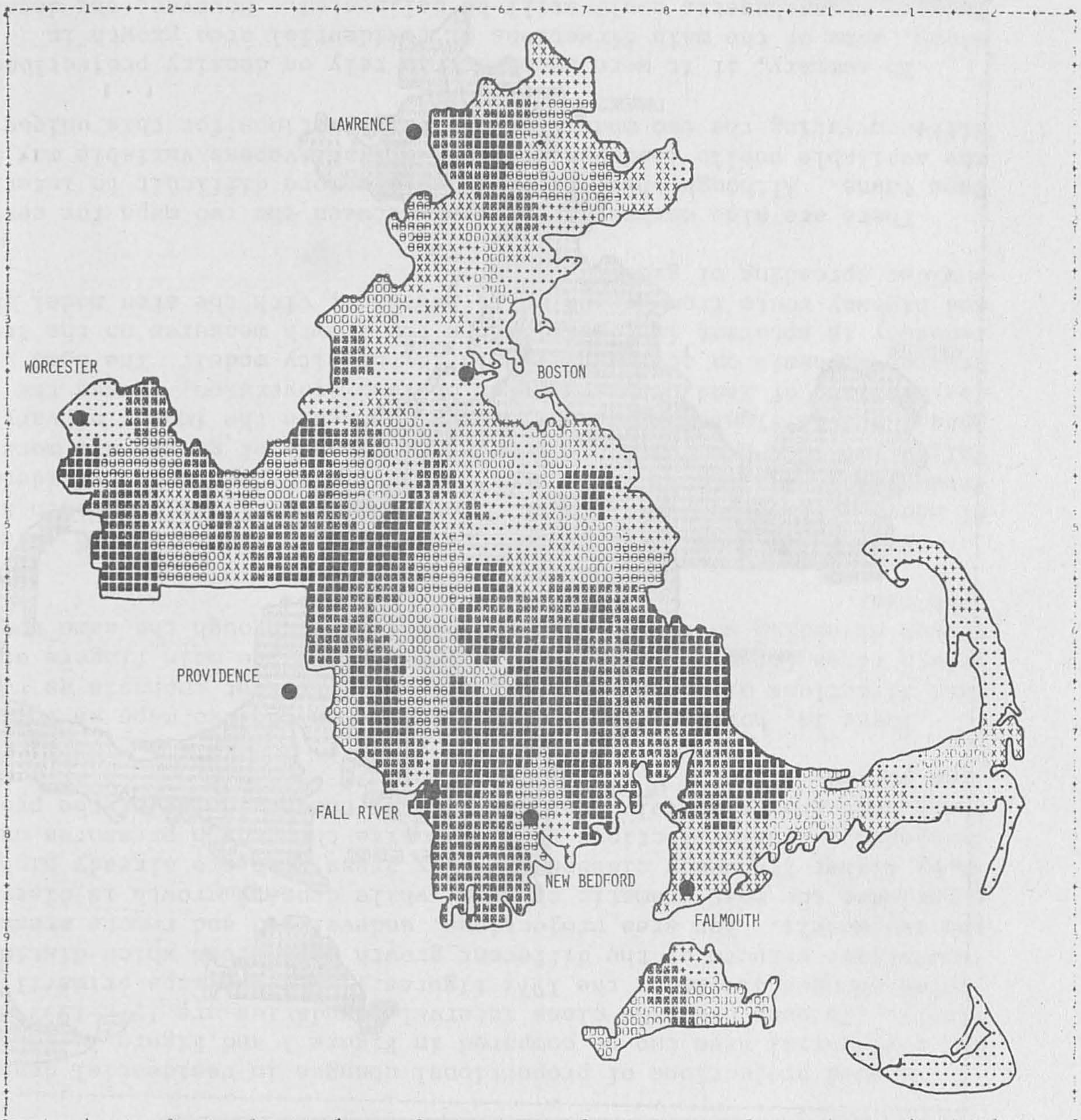


FIGURE 1: PROJECTION OF PROPORTIONAL CHANGES IN RESIDENTIAL SHARES, 1972-1992

LEVEL	1	2	3	4	5	6	7	
FREQUENCY (NO. OF TOWNS)	35	13	27	23	16	30	22	
CLASS INTERVAL	-1.10	0.15	0.30	0.50	0.75	1.00	1.50	MINIMUM
	0.15	0.30	0.50	0.75	1.00	1.50	3.6[illegible]	MAXIMUM

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
("MAXIMUM" INCLUDED IN HIGHEST LEVEL ONLY)

of residential land consumption that the area model projects for the less developed towns in the region.

Conclusions

Elementary residential density models [10] provide a useful starting place in constructing a residential area forecasting model. Additional variables selected for the area model are designed to account for differences in the amount of land consumed by each housing unit. All of the variables that were expected to be important in explaining residential area growth display highly significant coefficients in the selected forecast equation.

Where land use is a major concern, direct estimation of residential land use has the obvious advantage of avoiding use of assumptions about the complex relationship between housing density and residential land area. Large differences between density and residential area projections emphasize this problem. These differences are due to a considerable extent to variables which have different weights and signs between the two models, as well as differences in variables selected for each model.

Other contributions of the area model include its ability to weigh the effects of different types of land availabilities on land use. The area model also measures impacts of past development on the way land is converted to residential uses. While density projections may have real value for some planning purposes, the area model focuses on hypotheses about loss of open space and the environmental amenities that go with it.

References

[1] Barber, Brian and John W. Green, "A Procedure for Determining Town Employment by Place of Work." U.S. Department of Agriculture, Economic Research Service, Administrative paper, 1974.

[2] Chapin, F.S., Jr., and S.F. Weiss, "Factors Influencing Land Development." Center for Urban and Regional Studies, University of North Carolina, 1961.

[3] Hansen, Walter G., "How Accessibility Shapes Land Use." Journal of the American Institute of Planners, 25: 73-76, March 1959.

[4] Ingram, Gregory and John F. Kim and J. Royce Ginn, with contributions by H. James Brown and Stephen P. Dresch, The Detroit Prototype of the NBER Urban Simulation Model. National Bureau of Economic Research, Inc., New York, 1972.

[5] Irwin, N.A., "A Review of Existing Land Use Forecasting Techniques." Highway Research Record, 88: 183-216, 1965.

[6] MacConnell, William P. and H. Ross Powell and Peter E. Young, "Remote Sensing 20 Years of Change in Massachusetts, 1951-1971." Massachusetts Agricultural Experiment Station, Bulletin No. 624, 1974.

[7] Swerdloff, Carl N. and Joseph R. Stowers, "A Test of Some First Generation Residential Land Use Models." Highway Research Record, 126: 38-59, 1966.

[8] U.S. Department of Commerce, Population and Housing Census, Computer Tapes, 1950 and 1970.

[9] U.S. Geological Survey, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." Professional Paper 964, Washington, 1976.

[10] Wilson, A. G., "Developments of Some Elementary Residential Location Models." Journal of Regional Science, 9: 377-385, December 1969.