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Residential Land Values and the Decentralization of Jobs

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Abstract

The land-value surface in suburban Washington, D.C., changed dramatically over the decade of the 1980s. This article explains these changes in terms of the decentralization of jobs versus socioeconomic trends. Contemporaneous correlation among selected variables needs to be controlled with reduced forms and SES techniques. But all explanatory variables except distance from some unchanged point are determined simultaneously. Predetermined variables control for this double-endogeneity issue.

Land values in 1990 have a U-shape with respect to distance from the U.S. Capitol Building after controlling for other variables. The data indicate that this is the result of demographic changes rather than the development of suburban employment nodes: polycentric SUE theory is rejected. Land values are an increasing function of lagged land values, a decreasing function of work at home. Moreover, work at home is attracted by low structural density and high socioeconomic status as well as low land values. This supports the argument that demographics and technological innovations have shaped the land-value surface; baby boomers are seeking low-density housing for work and family life.

Key Words: suburbanization, subcenters, polycentric urban form, technological change, simultaneous equations

1. Introduction

Recent decentralization of U.S. economic activity is well documented (see Bollinger et al., 1998; Sivitanidou, 1997; Downs, 1994). Rapid development of "edge cities" is a particularly dramatic form of decentralization (Garreau, 1991). McMillen and McDonald (1998, p. 158) report that the "five employment centers in the newer industrial/retail and edge-city categories had the largest employment growth rates over the 1980 to 1990 decade." In many metropolitan housing markets, decentralization is manifested in relatively rapid growth of peripheral land values while downtown prices stagnate or decline.

The classical negative gradient may not describe the response of land values to distance from employment subcenters. Arnott, Anas, and Small (1997) summarize scattered empirical evidence showing that

- There are many subcenters in both new and old cities (for example, 15 outside Chicago's city limits), so subcenter employment is widely dispersed.
- More than half of metropolitan area jobs are outside either the central business district or the subcenters. "The polycentric pattern, interesting and important though it may be, coexists with a great deal of local employment dispersion" (Arnott et al., 1997, p. 28).
- There is a great deal of cross-commuting, probably because households have idiosyncratic preferences for particular locations and because of job specialization.

Thus, it is quite possible that residential land values do not respond in any discernible way to any given employment center.

In the office market, a major engine of metropolitan growth, the relatively rapid growth of suburban employment has been documented by Ihlanfeldt (1997). According to Coldwell Banker, suburban office vacancy rates have declined over a 10-year period to 9.9 percent in the first quarter of 2000 as compared to 7.4 percent for the downtown's (www.cbrichardellis.com).[1] From the demand side, this may be viewed as a continuation of a long-term trend; suburban office employment has grown faster than office jobs in the downtown at least since the 1960s (see Hamer, 1974).[2]

Overbuilding of office space in the 1980s, combined with substantial slowing in the rate of growth of office employment, undoubtedly contributed to the suburbanization of office employment in the 1990s. The annual growth of office employment was 4.87 percent from 1980 to 1985, 2.83 percent from 1985 to 1990, and 1.75 percent from 1990 to 1996.[3] Office firms, faced with abundant choices of Class A space, may have simply revealed their preference for suburban space; these preferences were accentuated by changes in telecommunications and by the restructuring of large firms during the 1980s and 1990s. It may be that some agglomeration economies (such as proximity to information sources, vendors and customers) are now available through use of technology, without the need for spatial proximity.[4] At the same time, the diseconomies associated with urban locations (high crime, pollution, etc.) have not been reduced.

If people follow jobs, then the suburbanization of office employment is a major cause of relatively rapid growth in population and house values with increasing distance from the central city. On the other hand, technological or socioeconomic changes may motivate household suburbanization independently of access to jobs.

This article focuses on explanations for changes in the suburban residential land value surface in the 1980s (Figure 1). Explanations for a flattening of the land value gradient include (1) jobs that suburbanize in an unconcentrated pattern because of improvements in computers and telecommunications (the internet, fax, e-mail, and the like), (2) suburban subcenters that substitute for the face-to-face contacts once concentrated in the downtown; (3) downsizing and restructuring that has reduced the demand for large blocks of contiguous office space typically found in the downtowns; (4) improved transportation

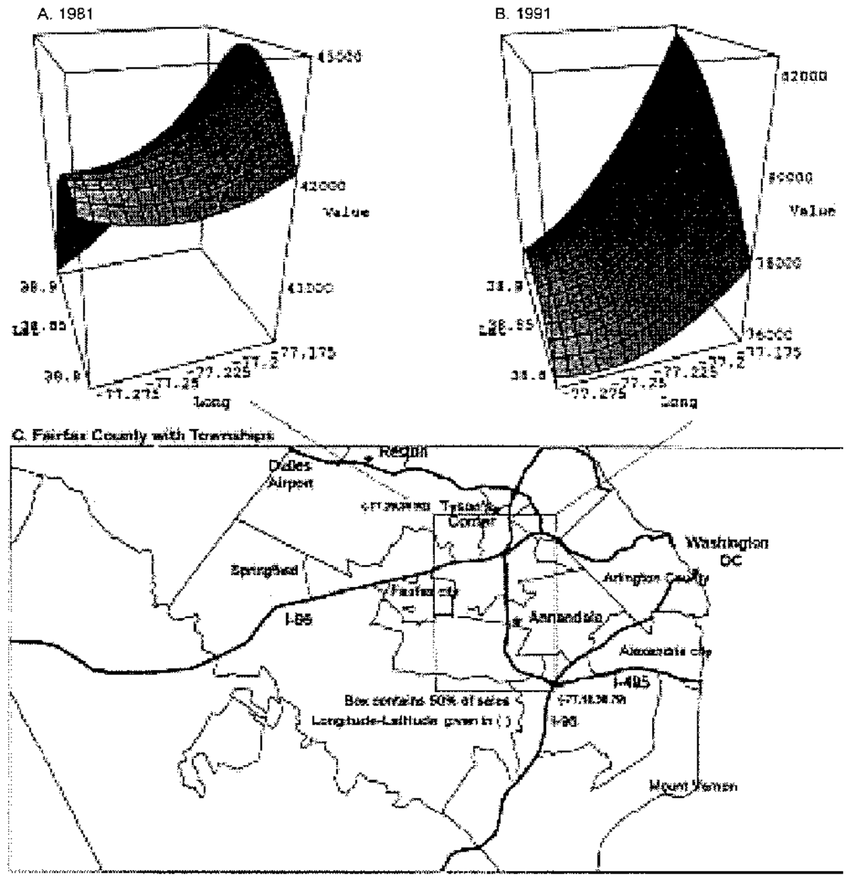

Figure 1. The Fairfax land-value surface, 1981 and 1991.

(such as safer and more comfortable automobiles) that has aided suburbanization of households; (5) demographic trends that are associated with the baby boomers and their decision to raise children in the suburbs; (6) increased agglomeration diseconomies such as congestion, high property tax rates, and crime in the central cities; and (7) "white flight" in response to high rates of poverty, deteriorating school quality, and concentrations of minority populations in the central cities. We focus on the role of the decentralization of jobs; we test for the importance of this explanation compared to socioeconomic trends.

This article analyzes the residential land value (predicted land price) surface in Fairfax County, Virginia, a suburb that extends west from the Potomac River. This value surface changed shape dramatically, with land values in more distant suburban locations increasing much faster than those near the downtown over the 1980s. This is particularly surprising in light of the centralized nature of government jobs in the Washington, D.C., area.

We use data on access to jobs (such as work at home and short commuting time) to indicate the contribution of suburban jobs to the shape of the land value surface. Census data on poverty, population density, family income, and the like are used to indicate the role of socioeconomic factors in suburban housing demand. The endogenous nature of these two groups of factors is assessed using simultaneous equation statistical techniques.

There are two components to the modern theory of land value. Urban land value is created by (1) accessibility to jobs, recreation, shopping, and social amenities and (2) the option to build on vacant land.

We use hedonic price index methods to isolate the value of land under developed residential structures. Since we confine our study to land under existing structures, we assume that option values are small. That is, the option to redevelop the land that we examined is far out of the money because of high transactions costs.[5] We estimate how changes in the location of jobs, work at home, and other socioeconomic characteristics are related to the 1990 cross-sectional pattern of land values.

The remainder of this article is organized as follows. Section 2 reviews the basic elements of the standard urban economics framework (SUE). Section 3 explains empirical issues related to the SUE framework and describes estimation equations. Section 4 describes the data and empirical results. Section 5 reports the results of sensitivity tests, and Section 6 provides concluding remarks.

2. The theory of land value

Land value is a residual after construction costs are subtracted from the present value of rents or, for owner-occupied residential land, from implicit use value. Therefore, land value is derived from the rental value of the structure; supply and demand for the developed property (that is, the residential structure and its location) gives value to the underlying land.

Our strategy is to develop a reduced form equation for land value. We focus our econometric modeling on the simultaneity that occurs between demand, supply, and land value. For example, population growth increases land value, but population tends to grow faster in response to lower land value.

The supply of residential structures for a neighborhood is given by the amount of available vacant land, zoning regulations, previously constructed houses, construction costs, and the sales prices of new units. By including the number of units previously constructed, we emphasize that urban density patterns are not costlessly malleable. A density given by historical supply and demand may persist because of the high costs of redevelopment. Furthermore, these existing units may not be of the same design or quality as those built in the current market.

The demand for housing can be developed within a standard urban economics (SUE) framework.[6] This theory says that there is a tradeoff between accessibility to jobs and the price paid for residential land; also, demand at any location is a function of income, family size, and other demographic characteristics. The land-value surface at any point in time should reflect commuting costs, income, and demographics.

This basic framework has been generalized for multicentric employment nodes (Arnott et al., 1997). Suburban employment nodes substitute for the agglomeration economies associated with downtown locations; for example, infrastructure costs are shared among the businesses at the suburban center. Land near subcenters may become as valuable or more valuable than land downtown. Thus, land-value gradients may follow a U-shaped pattern, declining with distance from the downtown and then rising with proximity to a suburban subcenter. If the subcenter develops enough agglomeration economies to dominate the traditional center, then the land value gradient can slope upward with increasing distance from the downtown.

The SUE literature discusses several factors likely to cause a shift upward in suburban land values as compared to CBD values (that is, a shift in the value gradient):

- Improvements in interstate highways and automobiles make it easier to commute from suburban employment centers. Narrow downtown streets developed during an earlier era are placed at a relative disadvantage.
- Baby-boom demographics have increased the demand for newer housing, larger structures, and larger yards for raising children.
- Increases in income have an ambiguous effect; increased demand for space and for high-quality government services must be balanced against increased opportunity costs of transportation.

To the extent that suburban employment can be freely substituted for traditional downtown jobs, increases in income will unambiguously increase the demand for suburban space. Thus, examination of the decentralization of jobs may provide an important explanation for the shape of the land value surface.

3. Empirical implications of SUE theory: the double-endogeneity problem

The land-value surface at a given point in time responds to current and lagged values of explanatory variables; history leaves an impression on the value surface.[7] The cross-section of land values captures this dynamic process at one point along its adjustment path. We use the land-value surface to make inferences about the dynamic process.

By way of contrast, Case and Mayer (1996) made plausible assumptions about the effects of explanatory variables (such as income, population density, school quality, and the like) on *change in* land values. This is a reasonable strategy given their orientation toward dynamic analysis and forecasting.

We are testing hypotheses about suburbanization. Therefore, we evaluate the response of the land-value surface to the accessibility and socioeconomic characteristics indicated by SUE theory. We capture the influence of dynamics on the land-value surface by using a transfer function framework. Lagged dependent variables indicate the degree of adaptation (a form of error correction) for each dependent variable.

We begin with a basic supply and demand framework. On the supply side we have

$$S = f \text{ (zoning, existing supply, available land, construction costs, land value, product price).} \tag{1}$$

Since direct measures of zoning are not available, we propose to approximate zoned land divided by available land with population density.[8] The density of existing supply of housing is measured by the percent of housing in structures with four or more units. Construction costs enter as a trend term (constant at a given point in time).

The demand side is given by equation (2); equilibrium by equation (3):

$$D = h \text{ (access to work, transportation infrastructure, taxes, government services, demographics, income)} \tag{2}$$

$$S = D. \tag{3}$$

3.1. *Accessibility*

Accessibility is measured by several variables, including distances to employment centers. We take distance to the traditional employment center as measured by the U.S. Capitol building in Washington, D.C. (DCAP). In addition, we include distances to two of the largest subcenters: Dulles Airport (DDUL) and Tyson's Corner (DTYS).

Accessibility to jobs has been improved by completion of the beltway around Washington, D.C., and by completion of subway lines extending into Fairfax County. We include a dummy variable (INBELT) which is 1 for all transactions within the beltway and 0 otherwise. We also include a dummy for locations adjacent to the Dulles access road (DULLESD).

Spatially diffuse employment subcenters should make surrounding land more valuable because of the short commute. Therefore, the percentage of workers with commuting time less than X minutes, where X depends on data availability, indicates proximity to an employment subcenter. Similarly, the role of telecommunications can be examined by modeling the percentage of the population working at home (WATHPC).

3.2. *Other explanatory variables*

There is relatively little variation in taxes or government services within Fairfax County because the county controls taxes and schools. Property-tax assessments are done countywide; there are very small variations in mill rates within the county.[9] While school boundaries within the county have changed over time, these changes have been related to socioeconomic characteristics rather than to resources. We use percent of population with a high school education or more (HSED) to evaluate socioeconomic characteristics.

Changes in housing demand are evaluated by changes in population density between 1970 and 1980 (PDCH80) and between 1980 and 1990 (PDCH90): We also measure family size to capture the tendency for baby boomers to move to newer, larger houses in the suburbs.

We measure income by median household income; after taking logs this is LNMH1. This is a more accurate measure of the demand for housing than per capita income.

3.3. *The double-endogeneity issue*

The left-hand sides of equations (1) and (2) should be measured by the flow of housing services. However, we lack adequate variables to measure quality-adjusted service flow. By estimating reduced-form equations we deal with the first endogeneity issue. Service flow is eliminated, and the dependent variable becomes the log of estimated land value in 1990 (LNSPHAT) or another variable of interest (such as population change).

The second endogeneity issue arises because many of the explanatory variables are interdependent. For example, growth in population density, a demand-side indicator, is influenced by the level of land values in each local area. Likewise, zoning responds to development pressure and telecommuters move to areas with low house prices, favorable zoning, and amenities (such as government services) for employees and residents. Potepan (1996) faced a similar problem of double endogeneity in the context of interurban land values.

Simultaneous estimation with lagged explanatory variables provides consistent estimators in the presence of the double-endogeneity issue. Contemporaneous variables are modeled with three-stage least squares; *all other variables* are lagged except unchanging variables such as distance from the CBD.

3.4. *The estimation equations*

A set of three simultaneous equations explain land value (LNSPHAT) together with changes in population density (PDCH90) and the percentage working at home (WATHPC90). Each equation in this system is part of the reduced form for equations (1) and (2); the simultaneous equations use predetermined variables to deal with interdependencies among explanatory variables.[10] There is no theoretical basis for identification of this simultaneous equation system. The SES is used only to control for endogeneity within the reduced-form equation.

This approach preserves the most important prediction of the SUE model: distance from the CBD determines urban form. Inclusion of this distance in all equations allows analysis of suburbanization after accounting for double endogeneity, socioeconomic characteristics, and so on. Thus, the equations become

$$\text{LNSPHAT} = f^r(\text{PDCH90, WATHPC90, DCAP, DCAPSQ, BLAKPC80, T10SH80, LNMHICH80, LNSPHAT8, PDCH80, WATHPC80}), \quad (4)$$

where variables are defined in Table 1.

The most important demand-side variable, growth in population density, is determined simultaneously with land rent:

$$\text{PDCH90} = f^d(\text{LNSPHAT, WATHPC90, DCAP, DCAPSQ, POPDEN80, HSED80, LNSPHAT8, PDCH80, WATHPC80}). \quad (5)$$

Finally, we deal explicitly with the role of telecommunications in terms of the ability it gives people to work from their homes. People are more likely to work at home where land values are low, housing density is low, houses are large to accommodate the home office, and socioeconomic characteristics are high (that is, a large percentage of well-educated workers):

$$\text{WATHPC90} = f^w(\text{LNSPHAT, PDCH90, BATH8, DCAP, DCAPSQ, HSED80, U3PCT80, LNSPHAT8, PDCH80, WATHPC80}). \quad (6)$$

Lagged explanatory variables are used as one way of dealing with the double-endogeneity problem. The 10-year lag, necessitated by the data, is long, but real estate markets are slow to adjust. If lagged explanatory variables are not significant, then the estimation strategy given by equations (4) to (6) will need to be reconsidered.

3.5. Employment subcenters

We do not have data on the spatial distribution of employment within Fairfax County. But, we do have census data on commuting time by place of residence. For each census tract, these data report the distribution of workers by commuting time.

We hypothesize that employment subcenters will leave an imprint on commuting time; average commuting time will be shorter for workers who are located close to the employment subcenter. We implement this by taking the percent of workers with short commuting times. "Short" can be operationalized by using those with commutes less than 30 minutes (for example: T30SH80 means percent with travel time less than 30 minutes in 1980) or the percent less than 10 or 20 minutes.

Table 1. Descriptive statistics.

Variable Label	N	Mean	Standard Deviation	Minimum	Maximum	
BATH8	150	2.56	0.40	1.54	3.82	Baths times D8 (1990 time dummy)
BLAKPC80	150	5.03	5.46	0.00	9.36	Percentage of population black in 1980
DCAP	150	0.22	0.08	0.10	0.43	Distance to U.S. Capitol (degrees)
DCAPSQ	150	0.06	0.04	0.01	0.19	Squared to U.S. Capitol (degrees)
DDUL	150	0.22	0.10	0.01	0.41	Distance to Dulles Airport
DTYS	150	0.11	0.06	0.00	0.26	Distance to Tysons Corner
DULLESD	150	0.08	0.27	0.00	1.00	Adjacent to Dulles Access Road (0,1)
FAMDEN80	150	805.75	610.38	2.38	3854.64	Number of families per square mile 1980
FDGVPC80	150	23.51	5.02	12.20	39.78	Percent employees working for federal government
FPLS8	150	1.06	0.39	0.12	2.38	Number of fireplaces in house, times D8
HSED80	150	59.25	13.58	23.34	81.16	High school education or better (%) in 1980
INBELTD	150	0.38	0.49	0.00	1.00	Inside the beltway (0,1)
LAGE8	150	2.13	0.84	−0.18	3.68	Log of building age times D8
LAT8	150	−0.01	0.07	−0.19	0.16	Latitude times D8 (1990 time dummy)
LATSQ8	150	0.01	0.01	0.00	0.03	Squared latitude times D8
LL8	150	0.00	0.01	−0.02	0.01	Latitude times longitude times D8
LNAREA	150	0.46	0.83	−1.58	2.94	Log of tract land area (acres)
LNGSQ8	150	0.01	0.01	0.00	0.06	Longitude squared times D8
LNMHI80	150	10.34	0.28	9.46	10.94	Log of median household income in 1980
LNMHICH8	150	0.76	0.19	0.35	1.28	Change, log median household income 1970 to 1980
LNPOP70	150	7.55	1.07	2.40	9.06	Log of tract population in 1970
LNPOP80	150	8.06	0.73	2.37	9.29	Log of tract population in 1980
LNPOP90	150	8.40	0.53	5.17	9.61	Log of tract population in 1990
LNSPHAT	150	10.10	0.04	9.98	10.21	Predicted log land value, 1991, equation (8)
LNSPHAT8	150	9.57	0.04	9.40	9.64	Predicted log land value, 1980, equation (8)
LONG8	150	0.00	0.10	−0.24	0.18	Longitude times D8
LRMD8	150	2.02	0.11	1.78	2.28	Log of number of rooms times D8
PDCH80	150	0.51	0.76	−0.40	3.08	Percent change in population per square mile
PDCH90	150	0.34	0.55	−0.28	2.80	Percent change in population per square mile
POPDEN80	150	3014.01	2357.23	9.20	14247.94	Population per square mile in 1980
SELFPC80	150	4.86	2.54	0.82	13.64	Percent of population self-employed
T10SH80	150	7.18	2.76	1.72	16.19	Percent of workers with commute < = 10 min.
T20SH80	150	28.20	7.48	5.95	43.59	Percent of workers with commute < = 20 min.
T30SH80	150	48.34	10.10	20.24	69.97	Percent of workers with commute < = 30 min.
U3PCT80	150	17.01	22.73	0.00	98.71	Percent of housing in structures with 4 + units
VEH2PC80	150	48.13	9.78	22.85	74.59	Percent of households with 2 or more vehicles
WATHPC80	150	1.94	1.29	0.00	7.70	Percent of workers working at home, 1980
WATHPC90	150	3.31	2.08	0.00	11.31	Percent of workers working at home, 1990

Note. Predicted values from equations (7) and (8) are summarized for the LNSPHAT variables. D1... D9 are 0,1 time dummies: D1 is 1 if the transaction occurred in 1975 to 1976, D2 is for 1977 to 1978, and D9 is for 1991 to 1992. This table reports variables multipled by D8 (1989 to 1990). Distances are in degrees, uncorrected for the earth's curvature.

3.6. An estimation form for land value

A dependent variable in this study is the estimated value of land under existing residential structures. Land value is extracted from a modified hedonic price index equation; the log of sales price (LNSP) for developed residential properties is regressed on time dummies and a vector of hedonic characteristics. The modification introduced here allows the implicit prices of hedonic characteristics to change each time period, and it estimates a two-dimensional spatial price surface at each point in time:

$$lnSP = f(\text{D1} \ldots \text{D9, LRMD1} \ldots \text{LRMD9, BATH1} \ldots \text{BATH9, FPLS1} \ldots \text{FPLS9,}$$
$$\text{LAGE1} \ldots \text{LAGE9, LONG1} \ldots \text{LONG9, LAT1} \ldots \text{LAT9, LNGSQ1} \ldots \text{LNSQ9,}$$
$$\text{LATSQ1} \ldots \text{LATSQ9, LL1} \ldots \text{LL9}), \quad (7)$$

where D1, ..., D9 are 0,1 time dummies: D1 is 1 if the transaction occurred in 1975 to 1976, D2 is for 1977 to 1978, and D9 is for 1991 to 1992. Each dummy variable is multiplied by each hedonic characteristic (such as log of number of rooms, LRMD) to form nine variables. Table 1 defines the variables in equation (7) and reports descriptive statistics for each variable multiplied by D8 (1989 to 1990). This specification allows the implicit prices of the hedonic characteristics to change over time.[11]

The land-value surface at each point in time is based on a Taylor's expansion around a central geographical point. A geographic information system (GIS) was used to assign latitude and longitude coordinates for each transaction. At any given point in time, the second-ordered Taylor expansion is

$$\text{LNSPHAT} = \text{Constant} + a\text{LONG} + b\text{LAT} + c\text{LONGSQ} + d\text{LATSQ} + e\text{LL} + \text{residual}, \quad (8)$$

where LL = LAT × LONG. Thus, LNSPHAT, the dependent variable in equation (4), is the predicted value from equation (8). Land value in 1990 is estimated by using 1989 to 1990 coefficients from equation (7) in equation (8); the constant term in equation (8) is the estimated coefficient on D8 from equation (7).

There are 91 explanatory variables in equation (7), even though the hedonic model includes only four characteristics. Thus, a large number of transactions are required to estimate the model.

4. The data and empirical results for land value

4.1. The data

The database for our study comes from the County Assessors' Office of Fairfax, Virginia. We use 60,544 transactions of single-family properties that sold from the first quarter of 1975 through the first quarter of 1992. Table 1 contains descriptive statistics for all variables with complete data after aggregation to the census tract level. In particular, all transactions had data within acceptable ranges for sales price and data of sale.

We controlled for heterogeneous property and locational characteristics with total rooms, bathrooms, fireplaces, and age of the structure. The GIS matched street addresses of the transactions with census tract boundaries; a 1990 census tract number was assigned to each transaction. Tables published by census were used to match 1980 tract boundaries to 1990 tract boundaries: where necessary, 1980 data were averaged or apportioned according to total population. Similarly, 1970 census data were allocated to 1990 tract boundaries.[12]

4.2. *Results for land value*

Figure 1 shows dramatic movements in the estimated land-value surface; it has become positively sloped with distance from south to north, especially to the northeast. The importance of distance from the U.S. Capitol building is weakening in percentage terms. The evidence in Figure 1 is consistent with Chicago: McMillen and McDonald (1998) find that distance to the downtown had less effect on residential land values in 1981 than in 1971, whereas distance to O'Hare Airport had a stronger negative effect. Moreover, distance to the nearest village hall had a negative effect much stronger than either the downtown or O'Hare.

The Atlanta data on office rents show a positive gradient with distance to downtown after controlling for building and lease characteristics as well as other locational variables (Bollinger et al., 1998). Given the importance of office employment in metropolitan development, this suggests that land rents may similarly increase with distance in a properly specified model.

4.3. *Results from the simultaneous equation system (SES) and OLS*

Equations (4), (5), and (6) were estimated by 3SLS, but the effects of lagged population density on land values and work at home were difficult to interpret.[13] Interpretation is facilitated by unbundling change in population (PDCHyy) into its components. For example, the left-hand side of equation (5) becomes LNPOP90 and the relevant right-hand variables are LNPOP80, LNPOP70, and LNAREA. The coefficients on these explanatory variables can be tested for the restrictions imposed by equation (5): the coefficient on LNAREA = 0 and the coefficients on LNPOP80 and on LNPOP70 must add up to 1. Similar restrictions can be tested for equations (4) and (6): the sum of the coefficients on LNPOP70, LNPOP80, and LNPOP90 should equal zero, and the coefficient on LNAREA should equal zero.

Table 2 contains the results from the unbundled model. The LNPOP90 equation shows that the coefficient restrictions imposed by equation (5) are not validated by the data: the sum restriction (TSTSUM) is rejected, as is the hypothesis that the LNAREA coefficient equals zero.[14] Moreover, the joint test of these two hypotheses rejects the null. Thus, the data support the unbundled specification for that equation.

Results for the lagged dependent variables show a strong autoregressive pattern in each equation. This illustrates the need to control for dynamic adjustment even though the main focus of the research in on cross-sectional relationships.

Table 2. Population change is unconstrained.

Dependent:	LNPOP90		LNSPHAT		WATHPC90	
Variable	Parameter Estimate	*t*-value	Parameter Estimate	*t*-value	Parameter Estimate	*t*-value
INTERCEP	− 7.731	− 0.772	7.232	10.153	196.842	4.326
LNPOP90			− 0.002	− 0.292	− 2.134	− 5.822
WATHPC90	− 0.098	− 5.950	− 0.008	− 6.090		
LNSPHAT	− 0.111	− 0.120			− 23.789	− 5.764
DCAP	− 4.883	− 1.736	− 1.024	− 4.268	− 60.402	− 4.730
DCAPSQ	10.346	1.916	1.980	4.269	105.140	4.240
LNSPHAT8	1.437	1.662	0.314	4.274	6.599	1.641
LNPOP70	− 0.192	− 4.655	0.015	3.801	− 0.196	− 0.948
LNPOP80	0.713	12.129	− 0.016	− 2.327	0.957	2.459
LNAREA	0.226	5.752	− 0.005	− 1.318	0.636	3.232
WATHPC80	0.072	2.652	0.006	2.540	0.616	5.237
HSED80	− 0.003	− 1.392			0.023	2.126
BLAKPC80			0.000	− 0.066		
T10SH80			− 0.003	− 2.440		
TSTSUM	F	139.695		0.383		31.939
	Prob > F:	0.000		0.536		0.000
TJOINT	F	70.571		2.514		16.106
	Prob > F:	0.000		0.082		0.000
System weighted *R*-square = 0.75						

Note. Variables are defined in Table 1. TSTSUM tests the restrictions imposed by PDCH90 and PDCH80 in equations (4), (5), and (6). For example, the LNPOP90 equation reported here corresponds to equation (5): the restriction is that the coefficients on LNPOP80 + LNPOP70 = 1. This specification is clearly rejected, but a similar restriction on the LNSPHAT regression—that the coefficients on all three LNPOP variables add up to zero—cannot be rejected. The TJOINT statistic adds the hypothesis that the coefficient on LNAREA = 0 to the sum hypothesis.

Distance displays a significant U-shaped effect on land values and work at home after controlling for endogeneity and for lagged explanatory variables. Distance has a negative effect on land values until 17.8 miles from the Capitol building; thus, the function is positively sloped over about 40 percent of the range of the data.[15] Land values decrease by 13 percent over the first 17.8 miles, and then increase about 5 percent. For the percentage working at home (WATHPC90) the distance function changes from negative to positive about 20 miles from the Capitol building; the percentage working at home increases over the most distant 10 miles of our data. Both of these results, together with the weakly significant result for population, confirm strong decentralization of land value and land use by 1990.

Higher percentages working at home (third equation, Table 2) are found in areas with low population, high land area, low land values, and high socioeconomic status (HSED80). All of these results are established by strongly significant coefficients on the relevant variables. The negative contemporaneous association between WATHPC90 and LNPOP90, given that we control for land area, indicates that those taking advantage of the new technology to work at home are seeking lower-density areas. Also, these workers, who have higher levels of education, choose to locate in more peripheral areas with lower land values and lower density of housing. Thus, all results support an upwardly mobile, educated workforce choosing to work at home in the distant suburbs.[16]

The separate effects of population and land area on 1990 population can be seen by transforming the LNPOP90 results in Table 2 as follows:

$$\begin{aligned}\text{LNPOP90} - \text{LNAREA} &= -7.73 - 0.25\text{LNAREA} + 0.71(\text{LNPOP80} - \text{LNPOP70}) \\ &\quad + 0.52(\text{LNPOP70} - \text{LNAREA}) + \cdots. \qquad (9)\end{aligned}$$

This shows that population density in 1990 is lower in larger census tracts and that population density responds positively to lagged population growth (elasticity equals 0.7) and to population density two decades earlier (elasticity equals 0.5). Thus, there was substantial persistence to the decentralization process in Fairfax County.

Theory argued that family size and poverty might explain land values. Neither variable was significant in any of the regressions that we estimated. This suggests that land values respond more to technological change than to family formation or poverty status. Change in the log of median household income has a positive effect on land values.

Table 2 shows that the SES deals with interdependencies among the three endogenous variables in a plausible way. In particular, work at home is negatively related to contemporaneous population and to land values. Comparing Table 2 to OLS regressions (not shown), the biggest changes are for the significance of the endogenous variables. The magnitude of the OLS coefficients on key endogenous variables are about half of the coefficients in Table 2. Thus, it is important to control for the double-endogeneity problem.

4.4. *The role of employment subcenters*

We found no evidence that concentrated nodes of suburban employment have influenced land values significantly in Fairfax County. The distance variables from Tyson's Corner (not shown) were not significant in any of the regressions that we estimated. Adjacency to the Dulles Airport corridor (DULLESD) was a factor, but it influenced land values and population *negatively*; also, land values and population increased with distance from Dulles Airport. So, SUE theory is not supported.

We use the proportion of workers with short commutes as another measure of employment subcenters. This variable was not significant in the population regression; it is negatively related to land values (LNSPHAT). This negative sign is opposite to that predicted by SUE theory; so the data support decentralization, regardless of commuting time.

Could the negative sign on travel share reflect short commutes for lower-income households? We doubt this in part because Fairfax is a suburban country without pockets of extreme poverty; the lowest median tract income in 1979 was $12,800. Also, we did include variables measuring median household income, house size, percent with a high school degree, and other indicators of socioeconomic status. However, the commuting variable persisted with a negative sign in the land value equation.

These results indicate that agglomeration economies available at suburban employment nodes do not explain the land-value surface. Instead, the data indicate that technological innovations have allowed employment and population to disperse in a relatively unconcentrated fashion. This supports the conclusions of Arnott et al. (1997, p. 56); metropolitan growth is dispersed throughout the suburbs.

5. Sensitivity tests

Two strategies can be employed for checking the sensitivity of the results in Table 2 to alternative model specifications:

- Try alternative combinations of explanatory variables. We entered the variables measuring distance to the Capitol building (the basic intuition of the SUE model) in various combinations for the three equations in the system. Examining coefficients under alternative specifications provides a simple form of Leamer's extreme-bounds approach.
- The system of three equations can be respecified as a recursive system by forcing the coefficients on the current endogenous variables to zero. This system is estimated by the seemingly unrelated (SUR) technique.

Tables 3, 4, 5, and 6 present the sensitivity tests using various combinations of distances (DCAP and DCAPSQ).[17] LNAREA is omitted and change in median household income (LNMHICH8) are included because these changes had a relatively large impact in the results. Other variables such as housing density (U3PCT80) are entered in order to fine-tune the estimates.

The results for distance reported in Table 2 are supported by the sensitivity tests in Tables 3 to 6. The distance pattern of endogenous variables is U-shaped after controlling for other variables. The highest level of significance is achieved in the land value (LNSPHAT) and work at home (WATHPC90) equations. Distance is best omitted from the population equation (Table 4 compared to 3 and 5).

The minimum point and shape of the land value gradient is robust to the specification changes in Tables 3, 4, 5, and 6. For example, the results in Table 4 show that land value declines by about 16 percent over the first 18 miles from the U.S. Capitol building and then increases by about 6 percent. The work-at-home percentage shows more variation. In Table 2, it declines by 8.7 percent over 20 miles and then increases by 2 percent over the remaining 10 miles. In Table 3, the turning point isn't until 26.4 miles, and the increase over the remaining 3.6 miles is only 3 percent. This variation probably reflects the small percent of the population that works at home.

Work at home in 1990 has an insignificant sign in the population regression but it usually has a significant negative sign in the land value regression (Tables 3, 4, and 5). This reinforces the conclusion from Table 2: those working at home are seeking low land

Table 3. Sensitivity tests: Base case.

Dependent:	LNPOP90		LNSPHAT		WATHPC90	
Variable	Parameter Estimate	t-value	Parameter Estimate	t-value	Parameter Estimate	t-value
INTERCEP	4.98733	0.23	7.25797	10.397	213.655	2.368
LNPOP90			−0.02376	−1.452	3.681	4.472
WATHPC90	0.07631	1.51	−0.01073	−3.492		
DCAP	−0.43816	−0.10	−1.21263	−4.675	−47.677	−2.798
DCAPSQ	6.12278	0.76	2.34743	4.449	62.225	1.875
LNMHICH8			0.03518	2.582		
LNSPHAT8	3.41924	2.16	0.32507	4.593	−8.243	−1.211
WATHPC80	0.00775	0.17	0.00708	1.866	0.417	3.113
LNPOP80	0.83128	10.29	7.77E-05	0.006	−3.625	−4.901
LNPOP70	−0.18505	−3.34	0.00931	2.227	0.948	3.467
LNSPHAT	−3.37678	−1.16			−13.811	−1.075
BATH8					0.207	0.952
U3PCT80					−0.014	−2.481
HSED80	−0.0169	−3.89			0.090	5.814

Note. All variables are defined in Table 1. System weighted R-square = 0.62.

values. One can infer that larger houses (with a room that can be used for work) are useful to those working at home, but the variables measuring house size (such as, BATH8) did not reach conventional levels of significance. Low density (measured by U3PCT80) and high socioeconomic status (HSED80) have positive effects on work at home. This confirms the expected pattern of decentralization based on new technology.

Table 4. Three-stage squares: Distance in LNSPHAT and WATHPC90.

Dependent:	LNPOP90		LNSPHAT		WATHPC90	
Variable	Estimate	t-value	Estimate	t-value	Estimate	t-value
INTERCEP	6.40756	0.46	7.34901	10.561	245.3123	2.67
WATHPC90	−0.03787	−0.94	−0.01279	−4.136		
LNSPHAT	−2.27442	−0.95			−20.3571	−1.54
LNSPHAT8	2.17715	1.45	0.31940	4.526	−4.1125	−0.58
LNPOP80	0.83826	11.16	0.00634	0.488	−2.7226	−3.07
LNPOP70	−0.27047	−5.49	0.00694	1.678	0.8379	2.83
WATHPC80	0.11773	2.98	0.00948	2.495	0.4441	3.17
HSED80	−0.01144	−2.90			0.0734	4.24
LNPOP90			−0.03169	−1.928	2.5144	2.47
DCAP			−1.23364	−4.783	−59.3204	−3.46
DCAPSQ			2.32866	4.433	93.3550	2.78
LNMHICH8			0.04192	2.925		
BATH8					0.2958	1.01
U3PCT80					−0.0206	−3.38

Note. System weighted R-square = 0.60.

Table 5. Distance in LNPOP90 and LNSPHAT.

Dependent:	LNPOP90		LNSPHAT		WATHPC90	
Variable	Estimate	*t*-value	Estimate	*t*-value	Estimate	*t*-value
INTERCEP	13.8794	0.653	7.2681	10.40	−38.4161	−0.585
LNPOP90			−0.0357	−2.15	−0.4116	−0.577
WATHPC90	0.0720	1.369	−0.0126	−4.03		
DCAP	−2.9227	−0.686	−1.2704	−4.86		
DCAPSQ	10.2491	1.288	2.5231	4.74		
LNMHICH8			0.0504	3.31		
LNSPHAT8	3.3467	2.107	0.3271	4.62	−6.0953	−0.854
WATHPC80	0.0107	0.224	0.0089	2.33	0.7405	5.414
LNPOP80	0.8348	10.303	0.0079	0.60	−0.2083	−0.292
LNPOP70	−0.1994	−3.606	0.0096	2.30	0.3470	1.132
LNSPHAT	−4.1478	−1.432			9.5850	0.844
HSED80	−0.0168	−3.766			0.0553	3.207
U3PCT80					−0.0104	−1.666
BATH8					0.4612	1.449

Note. System weighted R-square 0.59.

The important results established by equation (9) are confirmed by the sensitivity tests in Tables 3 to 6, where land area is omitted. Population decentralization is persistent over the two decades of our data. On the other hand, confidence in the negative relationship between working at home and population is weakened by the sensitivity tests: 1990

Table 6. Distance in LNPOP90 and WATHPC90.

Dependent:	LNPOP90		LNSPHAT		WATHPC90	
Variable	Parameter Estimate	*t*-value	Parameter Estimate	*t*-value	Parameter Estimate	*t*-value
INTERCEP	9.4074	0.554	5.1089	4.67	192.515	2.524
WATHPC90	−0.0415	−1.083	0.0050	0.88		
LNPOP90			0.0417	0.95	1.651	1.828
LNSPHAT	−1.0123	−0.475			−20.865	−2.167
DCAP	−7.1126	−2.074			−37.590	−2.232
DCAPSQ	18.0577	2.762			45.609	1.348
LNSPHAT8	0.5125	0.449	0.5151	3.96	2.240	0.424
LNPOP80	0.7380	10.747	−0.0601	−2.06	−1.340	−1.827
LNPOP70	−0.1371	−2.832	0.0296	3.38	0.145	0.568
WATHPC80	0.0628	1.414	−0.0085	−1.58	0.750	6.226
U3PCT80					−0.033	−5.221
BATH8					0.393	1.255
LNAREA			−0.0084	−0.70		
BLAKPC80			0.0018	2.52		
T20SH80			−0.0018	−3.92		
LNMHICH8			0.0365	2.12		

Note. System weighted R-square 0.59.

population has a significantly positive effect on WATHPC90 in two of the SES regressions in Tables 3 to 6. Thus, work at home responds more to low housing density than to low population density. This is consistent with working at home to facilitate child care.

Population in 1990 responds negatively to lagged socioeconomic status in Tables 3 to 6. This indicates that those neighborhoods with larger population have lower education, reinforcing the conclusion that those with higher education tend to seek low density housing. Moreover, WATHPC80 has significant positive effects on WATHPC90 and on land value (LNSPHAT) in 1990, confirming persistence over time in spatial patterns of decentralization.

6. Conclusions

We estimate an hedonic price index equation to determine the value of land under residential structures in Fairfax County at various points in time over the 1975 to 1992 time frame. We estimate cross-sectional regressions for 1990, but our theory recognized that this is a snapshot of a dynamic process. Lagged explanatory variables leave an imprint on the cross-sectional surface.

Our empirical methodology stresses the importance of dealing with the double-simultaneity issue. Contemporaneous correlation among selected variables needs to be controlled with a reduced form and SES techniques. But all explanatory variables except distance from some unchanged point are determined simultaneously. Therefore, it is important to use predetermined explanatory variables when estimating cross-sectional regressions over space.

The land-value surface has changed dramatically over time (Figure 1). The results of our simultaneous equation system show that it was U-shaped in 1990 with respect to distance from the U.S. Capitol building. The data indicate that this shape is the result of demographic changes rather than the development of suburban employment nodes.

The proportion of blacks in the population had either insignificant or significantly positive effects on land values after controlling for distance. This suggests that white flight has not been a factor within Fairfax County.

The Fairfax County data shows that land values are higher in areas with high lagged land values, lower in areas where a relatively high proportion of the population is working at home. Moreover, work at home is attracted to low structural density, low land values, and high socioeconomic status. This supports the argument that demographics and technological innovations have caused decentralization of the population; baby boomers are seeking low-density housing for work and family life.[18]

These results reflect the economic geography of Fairfax County, where the beltway, the Dulles corridor, and the subway system have allowed employment to diffuse outward in a relatively unconcentrated fashion. To the extent that employment growth has been concentrated, the results indicate that land values are negatively influenced by proximity to employment centers. Moreover, the remaining effect of distance on land values and work at home in 1990 is positive over the most distant part of our study area. This is opposite of the effect of commuting in SUE theory.

The Fairfax data are consistent with the results summarized by Arnott et al. (1997): large amounts of employment outside of employment centers and cross-commuting nullify the bid rent predictions of polycentric urban theory. Similarly, Sivitanidou (1997) finds substantial flattening of the office land value gradient from large subcenters in Los Angeles, 1989 to 1994. Bollinger et al. (1997) find a positive gradient from the downtown for office rents in Atlanta.

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Notes

1. Higher and more volatile employment growth in the suburbs implies the need for a relatively large inventory of available space.
2. We focus on office employment because it is the source of most growth or decline in U.S. metropolitan economies. For a summary of this, see Clapp (1993).
3. The author estimated the 1990s growth rate from national employment at the one-digit industry level. Earlier growth rates are taken from Rosen (1993, p. 163).
4. However, the comprehensive Atlanta data analyzed by Bollinger et al. (1997) show that access to downtown professional workers was nearly as important in 1996 as in 1990. "The evidence therefore is not supportive of the idea that telecommunications have diminished the role played by convenience for face-to-face interaction in determining office rents" (p. 23).
5. These costs include an extended period of vacancy while the house is being demolished and rebuilt. The authors have not observed any significant redevelopment in Fairfax Country; large options values should be accompanied by substantial redevelopment activity over a 20-year period.
6. No purpose would be served by formal development of the SUE model here. The model is summarized by Fujita (1989). A relatively brief, cogent summary is given in Arnott et al. (1997).
7. Consider one time-series model for each neighborhood. Then we take a snapshot of land values and related variables across all neighborhoods. The values at location A relative to those at B will be determined by current and lagged values measuring the built environment, population growth, and other explanatory variables in both neighborhoods.
8. Table 1 defines variables and gives descriptive statistics.
9. Variations in mill rates depend on leaf collection, a community center assessment, gypsy moth control, and a refuse tax. Of these, only the refuse tax attains a magnitude of more than 0.03 percent of property value. The few districts that do not pay a refuse tax (a flat $240 in 1997) have a corresponding reduction in public services.
10. We do not estimate a cross-section for 1980 because of insufficient lagged variables.
11. This is related to a model proposed by Shiller (1993) for repeat-sales regressions. The model is known as the hedonic repeated measures (HRM) approach.
12. Limited 1970 data were available because it needed to be entered manually.
13. These results, together with a discussion from an earlier draft of this article, are available on request. We do not claim to have identified the three equations; theory is not available for this effort. But we have reasonable interpretations of results from the SES system.
14. TSTSUM is for the sum of LNPOP80 and LNPOP70 coefficients. TJOINT is for the joint hypothesis that the

coefficient on LNAREA is zero and that the sum on the LNPOP variables is consistent with theory. The interpretation of TSTSUM and TJOINT for the other two equations in Table 2 is strictly analogous.
15. We observe transactions from 7 to 30 miles from the Capitol; the mean observation is 15 miles out.
16. Table 1 shows that those working at home were a small but growing percentage of all workers.
17. Estimates of a recursive system using SUR techniques support the conclusions observed in Tables 2 and 3; they will not be presented.
18. Neither family size nor poverty were significant in our regressions. But change in the log of median household income, lagged 10 years, has a positive effect on land value.

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