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THE SPATIAL CONSEQUENCES OF AUTARKY IN LAND-USE REGULATION: STRATEGIC INTERACTION OR PARALLELISM?

By

Paavo Monkkonen
John M. Quigley

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UNIVERSITY OF CALIFORNIA, BERKELEY

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Paavo Monkkonen
University of California
Berkeley, CA
paavo@berkeley.edu

John M. Quigley
University of California
Berkeley, CA
quigley@econ.berkeley.edu

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Abstract

In most of the United States, land-use regulations are determined independently by the cities and towns within a metropolitan housing market. Despite theoretical analysis of the interaction among regulatory decisions across jurisdictions, empirical evidence is limited. In this paper, we explore the spatial distribution of specific categories of land-use regulations based upon original data collected for the San Francisco Bay Area. We document the strong positive autocorrelation which characterizes regulations enacted independently by local governments in nearby cities. This spatial autocorrelation is somewhat weaker, but still significant, when the demographic determinants of land-use regulations are controlled for in autoregressive models. Similar results have previously been interpreted as evidence of strategic interaction among local governments. However, it is also true that the demographic characteristics of neighboring cities are highly correlated. When both of these factors are recognized in appropriate statistical models, we find no evidence of a spatial relationship among land-use rules. This casts doubt on the importance of strategic interaction in the enactment of land-use regulations.

Keywords: Spatial autocorrelation, growth control measures, strategic interaction

JEL codes: R52, L51, C21

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The Spatial Consequences of Autarky in Land-Use Regulation: Strategic Interaction or Parallelism?

I. Introduction

The regulation of land use in most urban areas of the United States does not occur at the metropolitan level. Local jurisdictions in most states have almost complete control over land-use regulation within their boundaries. Since metropolitan areas are typically composed of tens or hundreds of jurisdictions of varying sizes, it is not surprising that these regions exhibit great variation in the stringency of land-use regulation within their borders. Moreover, it is generally supposed that the lack of coordination in land-use regulation, combined with strategic implementation of ordinances that limit growth or density, has untoward effects on population growth patterns, leads to the exclusion of low-income households from some communities, and results in higher housing prices overall.

Metropolitan regions in California provide an extreme example of the uncoordinated spatial distribution of land-use regulation, as their constituent jurisdictions are almost completely autarchic. Previous research on land-use regulations in California has demonstrated that the stringency of regulation at the city level has significant and important effects on housing prices and demographics throughout the state. In this analysis, we focus on the spatial patterns of land-use regulation within the San Francisco Bay Area. We test whether the observed spatial pattern of land-use regulations across cities is the result of the spatial autocorrelation of their demographic characteristics, or is a consequence of the interaction among the regulatory policies adopted by city governments.

Initially, we estimate models similar to those previously applied to investigate the interaction between local government policies. We find that the number of development caps enacted by cities is positively correlated over space, and the level of density limitation imposed by a city, measured by the minimum lot-size for development, is negatively correlated over space. We consider two other regulatory variables: the number of approvals or reviews needed to obtain a permit to build and the number needed to secure a zoning change, but find that there is no significant autocorrelation over space when the demographic characteristics of the city and its neighbors are controlled for appropriately. Additionally, we examine the spatial patterns of building permits issued during the period from 1990 to 2006 for the same cities and find that there is significant, positive spatial correlation in permits issued for single-family houses and for all residential units when controlling for each city's own demographic characteristics.

However, in a series of models that test the impact of neighbors' policy decisions on the regulations enacted by a city, while controlling for that city's demographic characteristics as well as the demographics of neighboring cities, spatial autocorrelation is not significant. This implies that the influence of policy decisions or the permitting activity of neighboring jurisdictions on the number of land-use regulations enacted or building permits issued by a city cannot be isolated and identified, due to the strong spatial autocorrelation in the determinants of land-use regulation. Thus, despite the spatial autocorrelation in the regulatory decisions of cities, we find no credible evidence of strategic interaction among governments in the region.

In the following section, we examine the link between political fragmentation, land-use regulation, and spatial outcomes. We synthesize theories and findings by economists and planners linking these phenomena. Section III considers these issues in the specific context of California's San Francisco Bay Area. We exploit newly assembled data detailing the land-use regulations enacted by more than 75 jurisdictions in the Bay Area, the building permits issued by these jurisdictions, and their demographic characteristics. Section IV presents a series of empirical models describing the spatial pattern of land-use regulations adopted independently by nearby jurisdictions. We distinguish between strategic interactions in the adoption of regulation by nearby cities and the influence of the similar demographic conditions observed in neighboring jurisdictions. Section V is a brief conclusion that discusses directions for future research.

II. The Impacts of Politically Fragmented Land-Use Regulation on Urban Growth, Segregation, and Housing Prices

A growing body of empirical research focuses on the impact of land-use regulation on three outcomes: urban growth patterns, the spatial distribution of demographic groups, and housing prices. The politically fragmented nature of land-use regulation in most metropolitan areas is central to much of this analysis, as it is the variation in the regulatory stringency in different places (metropolitan areas or the jurisdictions within them) that is linked to variations in housing prices, growth patterns, and levels of segregation. Much of this research has been conducted at the metropolitan level. As noted, however, land-use regulation is quite often controlled by city governments, and there are typically a large number of local governments in any given metropolitan area. Moreover, this intra-metropolitan political fragmentation in land-use regulation gives rise to some of the more important and complicated impacts of the regulatory system.

The study of 'sprawl' and its causes has addressed the question of political fragmentation most explicitly. For example, Fulton and his colleagues found that, in metropolitan areas with more fragmented local governments, more land was converted to urban use to accommodate a given level of population growth (Fulton et al. 2001). Carruthers (2003) has developed a conceptual model indicating how the politically fragmented landscape leads to less dense patterns of growth. Land-use regulation in cities in the interior of a metropolitan area pushes new growth to the peripheral areas. After the passage of time, these outlying areas incorporate as cities with the power to regulate land use and thus to push growth further out again. In a test of this model, Carruthers finds significant, positive effects of municipal fragmentation on the percentage of metropolitan population change that occurs at the urban fringe.

The connection between land-use regulation and high housing prices is most apparent in metropolitan level comparisons, and is evident using simple graphical analysis (Malpezzi, 1996; Quigley, 2007). In two recent studies which focus on cities in Florida and the San

Francisco Bay Area, it has been shown that variation in land-use regulation at the city level within metropolitan areas is linked to higher housing prices. Both studies use instrumental variables techniques to account for the endogeneity of regulation in a hedonic model of housing prices. Both find a significant and positive relationship between indicators of regulatory restrictiveness and housing prices (Ihlanfeldt 2007; Quigley, Raphael, and Rosenthal 2007).

Three quantitative studies of California cities provide evidence of 'exclusion' attributable to strict land-use regulation, which leads to increased levels of segregation of low-income and minority households (Donovan and Leiman 1992; Levine 1999; Quigley, Raphael, and Rosenthal 2004). Using a survey of 147 California cities, Donovan and Neiman (1992) show that an increase in the fraction of Black residents in a city is negatively associated with the number of regulations enacted. Using a similar but more comprehensive survey with a larger sample of California cities, Levine (1999) reports similar results, and he also extends the analysis to address the distribution of income and the share of a city's population that is Hispanic. In a more recent analysis of the issue, Quigley et al. (2004) show that land-use regulation which favors the development of single-family housing is associated with decreases in the proportion of the minority population in cities in the Los Angeles Metropolitan Area.

Only one study has analyzed the spatial association of land-use regulation across cities. Brueckner (1998) uses data on cities across California to test for an interaction between the growth control measures adopted by one city and those adopted by neighboring cities.

Using a spatial autoregressive (SAR) model, Brueckner finds that - under reasonable conditions - a variable measuring local growth control limitations has a significant effect upon similar measures adopted by other cities.

There are two major problems in interpreting Brueckner's results. First, the distance thresholds used for the spatial analysis are quite high - 50 and 100 miles. The idea that the decision by one city to impose growth controls is influenced by the decisions of cities 100 miles away is implausible – the land-use regulation decisions made by the city of San Francisco are not influenced by those made by the city of Sacramento. Second, Brueckner's model does not recognize the spatial autocorrelation of the demographic characteristics of cities, and the possibility that the observed spatial correlation of the regulations adopted by neighboring cities may arise simply from the similarity of their socio-demographic characteristics and underlying citizen preferences. We address these two problems in the empirical analysis reported below – using new data on several distinct aspects of land-use regulations imposed by cities of the San Francisco Bay Area.

III. The Metropolitan Context and the Data

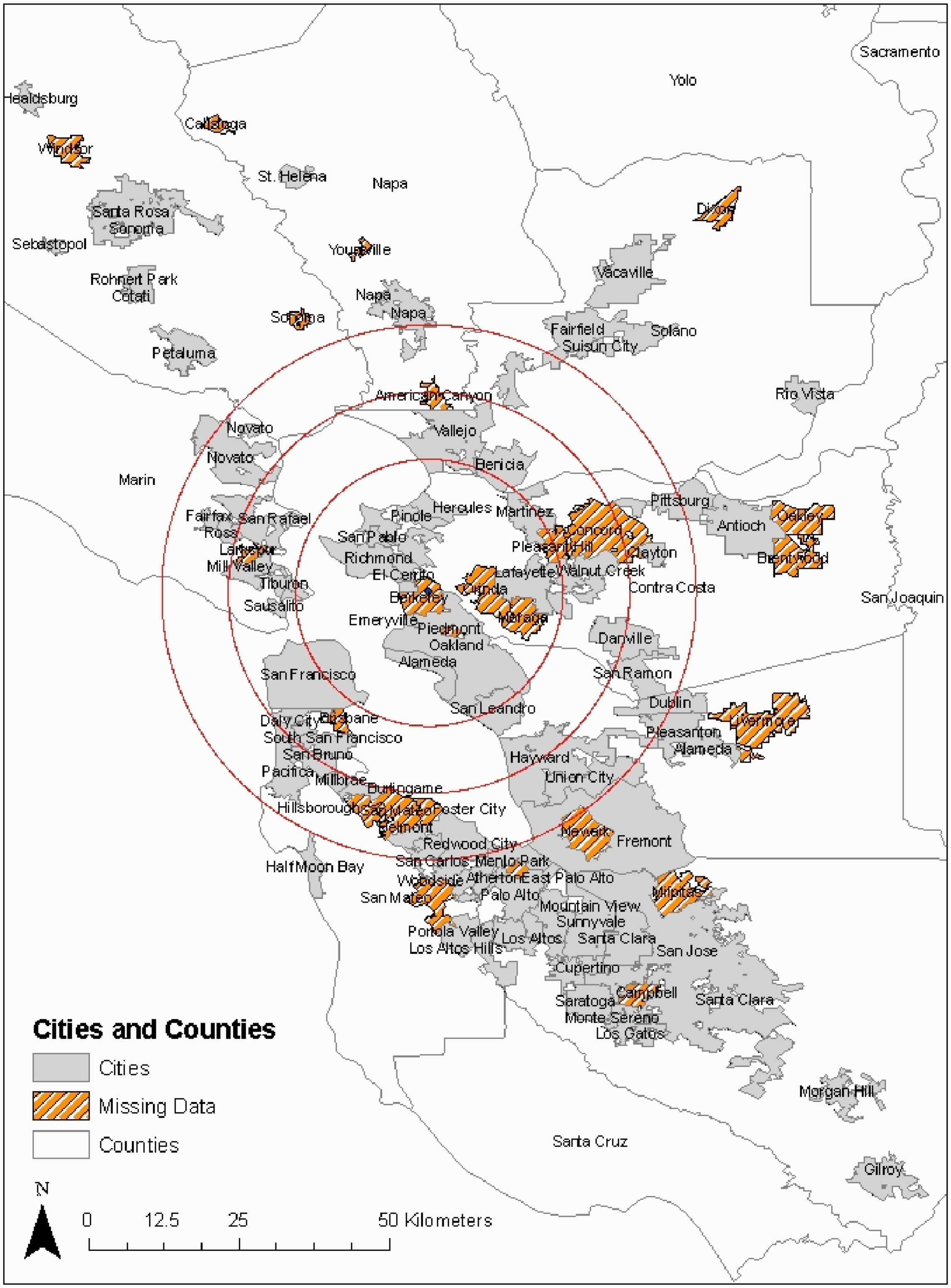
The San Francisco Bay Area includes over one hundred separate and independent land-use jurisdictions. The nine counties that define the Bay Area have authority over land-use decisions in their unincorporated areas, while the 101 incorporated cities control the land use within their boundaries. The San Francisco Bay Area has received considerable attention in the study of land-use regulation because it is one of the most heavily regulated metropolitan landscapes in the world. It also contains some of the most expensive housing in the United States.[1] The Bay Area is also notable in that it has more open space and preserved greenbelt than any other metropolitan area in the United States, due both to its unique geography and its history as home of the conservation movement (Walker 2008).

The regulatory data analyzed below were collected as part of a survey conducted in 2006/2007.[2] The survey was administered to public officials in the planning offices of city and county governments, and the responses were corroborated by developers, builders, and environmental consultants in the local area. The survey asked a variety of questions about the political influences on land-use regulation, the process of project approvals and zoning changes, the enactment of specific ordinances to control growth or to restrict development, and the average rate of delay and rejection of proposed-development projects. The response rate of public officials on the survey was quite high (79 percent).

We use responses from 76 of the 77 cities for which complete data are available.[3] Figure 1 shows the cities and counties of the San Francisco Bay Area, and indicates those cities for which data are not available. The Figure also shows distance boundaries of 20, 30 and

[1] In the terminology of Gyourko, Mayer and Sinai (2006), San Francisco is the prototypical 'superstar city,' characterized by high housing prices, land scarcity and the in-migration of high-income families.
[2] For detailed information on the methodology, see Calfee et al. (2007).
[3] One city, Brentwood, granted five times the number of residential building permits between 1990 and 2006 than it had dwellings in 1990. This was four times more than the next highest city. We exclude it from the analysis reported below.

Figure 1
Cities and Counties Surveyed in the San Francisco Bay Area



40 kilometers around the city of Berkeley in order to illustrate the different spatial neighborhood thresholds that will be used later.

The survey instrument represents one of the most comprehensive attempts to measure land-use regulation to date. Nevertheless, transforming qualitative survey responses on regulation into quantitative measures of restrictiveness is challenging (see, for example, Gyourko, Saiz and Summers, 2008). The state of the art in this enterprise remains the simple summation of ordinances in some category of regulation, such as growth control. This yields a meaningful measure, e.g. the number of growth control regulations, which can be used to test the impact of growth controls. However, some categories of regulation have proven more difficult to quantify meaningfully, and a consistent method for combining categories into an overall index of regulatory restrictiveness remains elusive.[4]

In our empirical analysis, we focus on four subsets of questions in this survey: the approvals needed for obtaining a permit for a new housing project; the approvals needed for a change in the zoning code; the presence of caps on residential development; and the restriction of density through minimum lot-size ordinances. Tables 1, 2 and 3 describe the responses to these questions. Table 1 presents the responses to questions about reviews needed for project approval and for zoning changes. The vast majority of cities require approval from the Planning Commission, the Building and Fire Departments, and a California Environmental Quality Act (CEQA) review for all projects. In addition,

[4] In an earlier paper on the house price impacts of land-use regulation that used the same survey data, such an index was constructed, the Berkeley Land Use Regulation Index (Quigley et al. 2008). However, it was subsequently demonstrated that sub-indexes of different categories of regulation were preferable as measures of regulatory strictness.

slightly more than half require some sort of architectural or design review. The most prevalent type of approval needed for a zoning change is from the Planning Commission and City Council, required in almost every city surveyed. In addition, a surprisingly high number of cities require a growth management analysis and an approval from the Health Department for a zoning change. Other reviews or approvals required by cities include a public benefits review, Police Department approval, a geotechnical assessment and approval from the California Coastal Commission.

Table 1
Number and Percent of Cities Requiring Project Approval or Review by Various Public Bodies

	A. No zoning change		B. Zoning change	
Approval or Review by:	**Number**	**Percent**	**Number**	**Percent**
Planning Commission	57	75	72	95
City Council	18	24	74	97
Landmarks/Historical Commission	11	14	1	1
Architectural/Design Review	45	59	7	9
Building Department	64	84	42	55
Fire Department	64	84	59	78
Health Department	19	25	60	79
Parking/Transportation	21	28	20	26
CEQA Review	62	82	26	34
Growth management analysis	12	16	67	88
Other	16	21	16	21

Table 2 shows the number and percent of jurisdictions that have enacted different types of caps on development. Caps placed on the number of new units allowed or new building permits granted are the most prevalent. Only four places have enacted a cap on population growth *per se*. Table 3 presents the range of minimum lot-size restrictions, also referred to as density restrictions. Most cities have some minimum lot-size requirement, though almost half merely limit lots to less than half an acre in size. But more than 40 percent of cities have minimum lot-size requirements of greater than half an acre.

Table 2
Number and Percent of Cities by Type of Development Cap Enacted

Category of Caps	Number of Jurisdictions	Percent of Jurisdictions
No development cap	58	76
Single-family building permits granted	12	16
Multifamily building permits granted	11	14
New single-family units	10	13
New multifamily units	10	13
Population growth	4	5

Table 3
Number and Percent of Cities by Lot-Size Restrictions Enacted

Lot-Size Restrictions	Variable Coding	Number of Jurisdictions	Percent of Jurisdictions
None	0	9	12
Less than ½ acre	1	36	47
½ acre up to 1 acre	2	13	17
1 acre to 2 acres	3	5	7
More than 2 acres	4	13	17

Tables 3, 4 and 5 describe the quantitative variables derived from these survey responses. As noted, Table 3 outlines the minimum lot-size variable, obtained by categorizing increasing sizes from 0 to 4. Tables 4 and 5 describe the cumulative number of approvals or reviews required and the number of development caps enacted by the local government. Not surprisingly, cities generally require more reviews and approvals for zoning changes than for projects that do not require a zoning change. Most cities in the San Francisco Bay Area have not enacted any development caps, but those that have enacted these caps generally adopt two or more.

Table 4
Number and Percent of Cities by Cumulative Number of Approvals Required

Number of Approvals Required	A. No zoning change		B. Zoning change	
	Number	Percent	Number	Percent
0	2	3	1	1
1	4	5	2	3
2	3	4	3	4
3	5	7	7	9
4	10	13	5	7
5	18	24	11	14
6	18	24	13	17
7	9	12	11	14
8	3	4	16	21
9	4	5	5	7
10	0	0	1	1

Table 5
Number and Percent of Cities by Cumulative Development Caps Enacted

Number of Caps	Number of Jurisdictions	Percent of Jurisdictions
0	58	76
1	2	3
2	10	13
3	1	1
4	3	4
5	2	3

The indexes summarized in Tables 3, 4 and 5 suffer from a problem inherent to the construction of quantitative indicators - they do not describe the stringency of a regulation exactly, rather the number of components it has. More ordinances need not mean stricter regulation; however, this is as good a proxy as is available. This limitation should be taken into consideration when interpreting results.

In addition to the data on regulations imposed by the cities of the San Francisco Bay Area, data on the number of building permits issued by these cities from 1990 – 2006 is available from the California Building Institute (2006). Table 6 summarizes descriptive information on selected demographic characteristics of the sample of 76 cities.

IV. The Spatial Distribution of Land-Use Regulations in the San Francisco Bay Area

Figures 2 through 5 present the spatial distribution of the measures of regulatory restrictiveness for cities in the San Francisco Bay Area. Figure 2 reports the number of reviews required for the approval of a new development project in each of the 76 cities. Figure 3 reports analogous information for the approval of a development project requiring a zoning change. Figure 4 documents the spatial distribution of the caps on development enacted by those same cities, and Figure 5 indicates the spatial distribution of density restrictions imposed by San Francisco Bay Area cities. Figures 6 and 7 present information on the housing permits issued by the same cities.

Table 6
Summary of Demographic Data for Cities Surveyed in the San Francisco Bay Area

Variable	Mean	Std. Dev.	Min	Max
Median household income (thousands of dollars)	75.83	31.42	37.18	200.00
Percent of adult residents with a college degree	21.78	10.25	5.23	41.98
Percent of dwellings that are owner-occupied	64.99	13.43	34.98	98.34
Percent of population under 18 years of age	25.43	4.82	7.00	34.00
Percent of population that is White	68.32	19.27	26.00	97.00
Single-family housing permits issued 1990-2006/ (Housing stock in 1990)	0.14	0.20	0.00	1.44
All permits issued 1990-2006 / (Housing stock in 1990)	0.19	0.23	0.00	1.46

Source: United States Census Bureau, 2000; California Building Institute, 2006.

Figure 2
The Number of Reviews or Approvals Required for Housing Development Projects in San Francisco Bay Area Cities

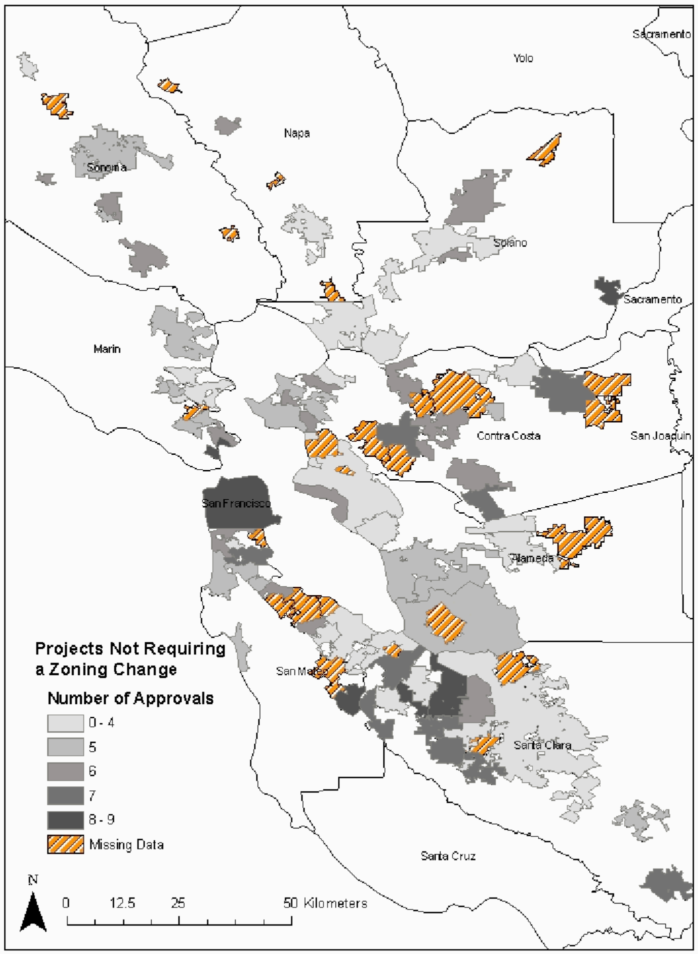


Figure 3
The Number of Approvals Required for Zoning Change in San Francisco Bay Area Cities

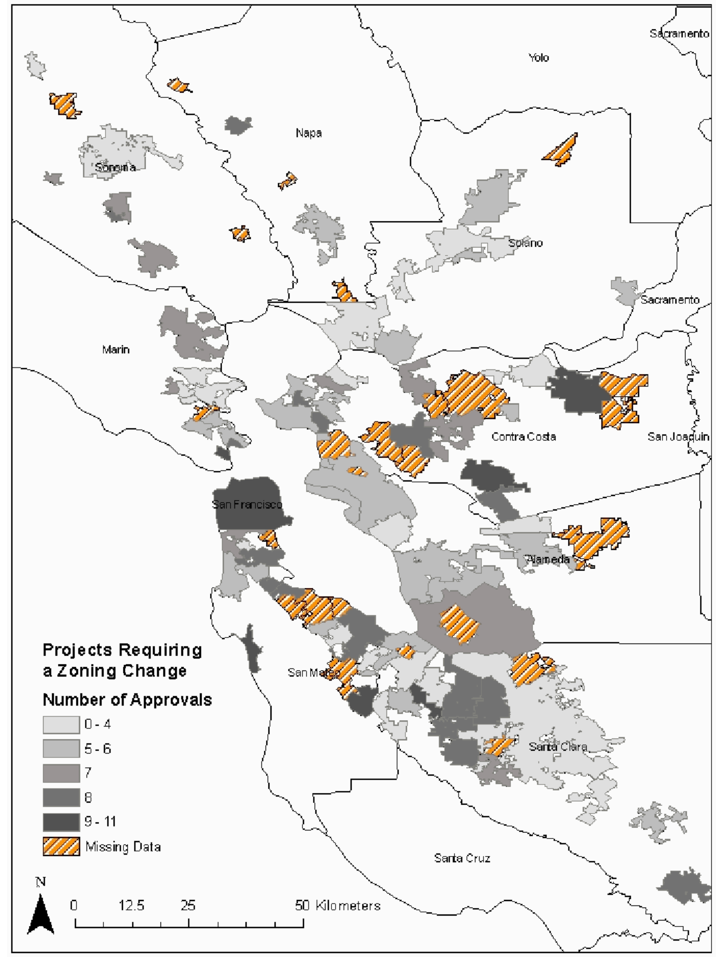


Figure 4
The Number of Development Caps Enacted in San Francisco Bay Area Cities

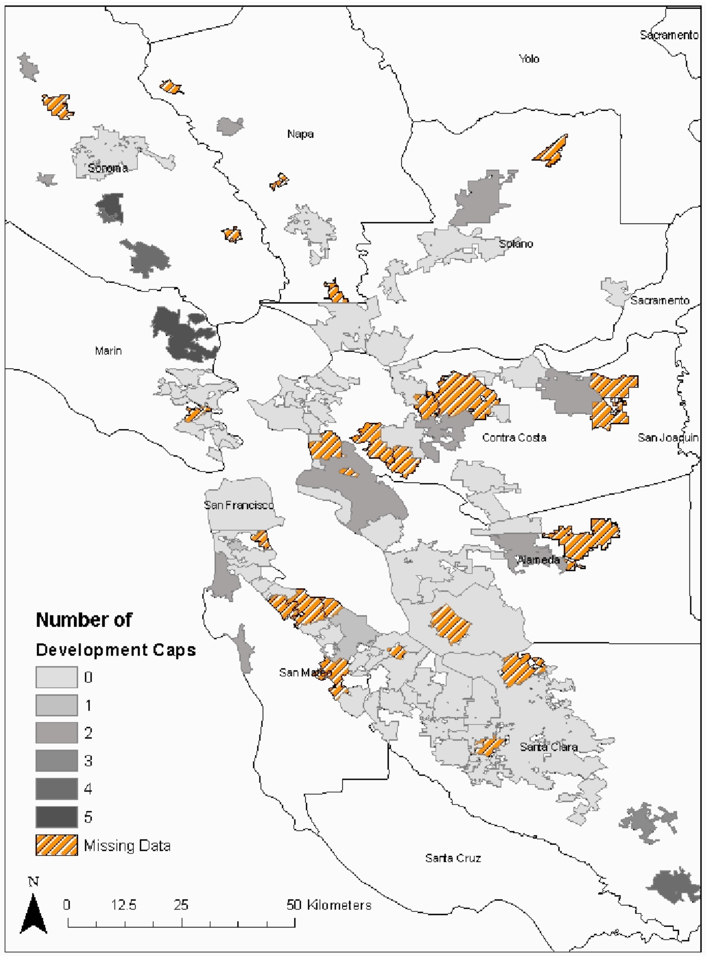


Figure 5
The Number of Density Restrictions Enacted in San Francisco Bay Area Cities

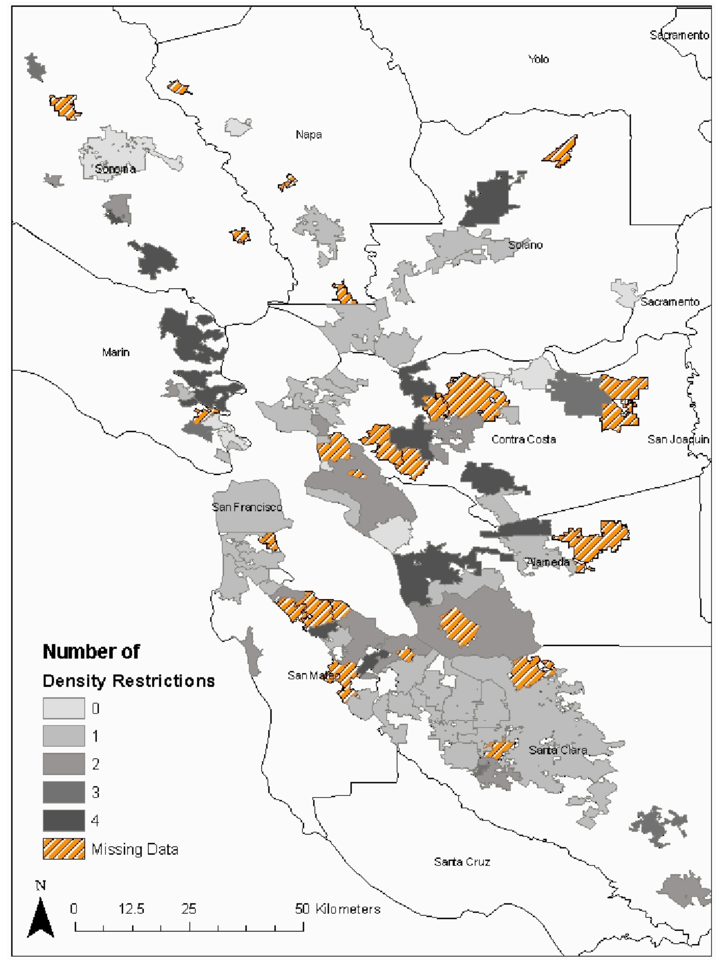


Figure 6
The Number of Single-Family Housing Permits Issued by San Francisco Bay Area Cities, 1990-2006 (as a fraction of Housing Stock in 1990)

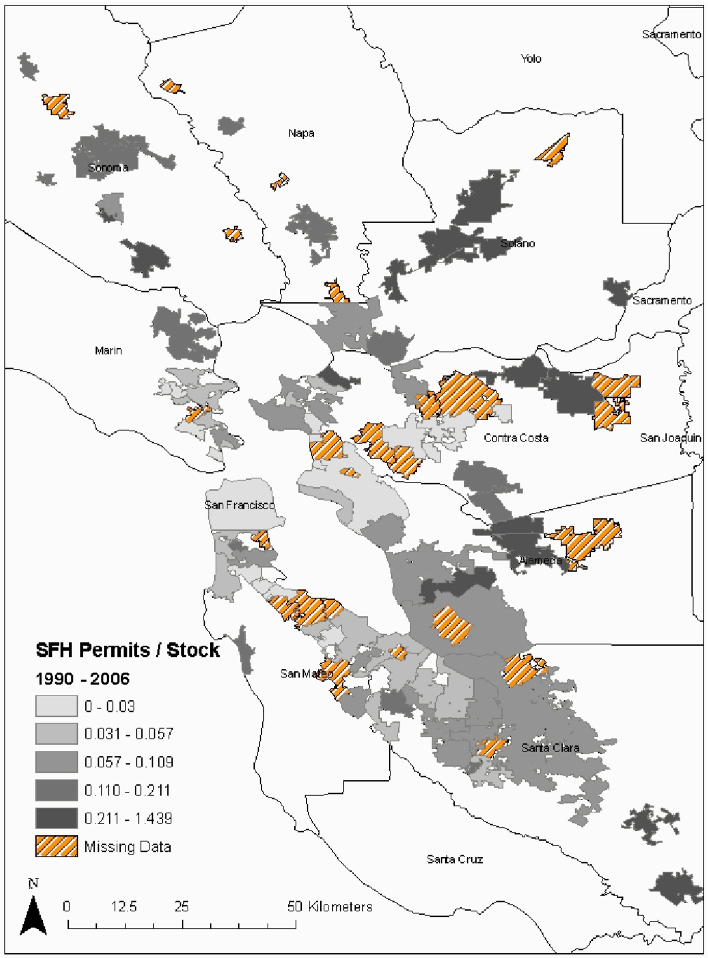
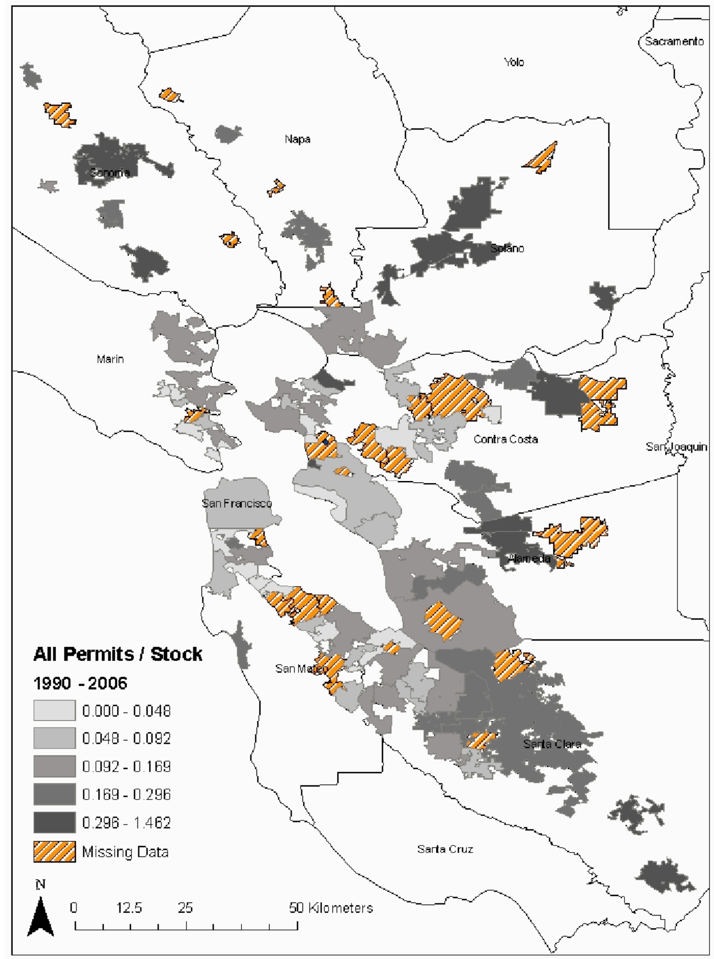


Figure 7
The Number of All Housing Permits Issued by San Francisco Bay Area Cities, 1990-2006 (as a fraction of Housing Stock in 1990)



In Figures 2 through 7 there appears to be a spatial association in the geographical distribution of regulations and permits across these cities. Clusters of cities with a high number of reviews required for project approval and zoning changes are evident north of San Jose, on the peninsula near San Francisco, in Sonoma County, and in central Contra Costa County. Clusters of cities with development caps are even more apparent in Sonoma and Marin County and in southern Santa Clara County. Cities with strict density restrictions are clearly clustered in the East Bay, and in Marin and Sonoma Counties. As expected, high numbers of building permits for single-family housing, and all residential construction, relative to the pre-existing stock of residences are found throughout the peripheral cities of the metropolitan area.

To investigate the extent to which land-use regulation is affected by the spatial relationships among these variables and the demographic characteristics of cities, we conduct four sets of tests. First, we analyze the spatial autocorrelation of the regulatory and permit variables, as well as that of the demographic variables. Then, we analyze simple autoregressive models using spatial lags and compare these to ordinary least squares statistical models of the determinants of regulatory stringency. Finally, based on the results of the autoregressive models, we incorporate spatial lags of some of the demographic variables in models known as spatial Durbin models (LeSage 1999).

Table 7
Spatial Autoregression Coefficients for San Francisco Bay Area Cities

		Inverse distance with cut off at:		
A. Demographic Characteristics	**Adjacent**	**20 km**	**30 km**	**40 km**
Median household income (thousands of dollars)	0.78**	0.89**	0.95**	0.96**
	(12.07)	(15.71)	(20.99)	(28.12)
Percent of adult residents with a college degree	0.81**	0.89**	0.92**	0.94**
	(14.10)	(15.85)	(14.16)	(16.92)
Percent of dwellings that are owner-occupied	0.76**	0.91**	0.99**	0.99**
	(11.05)	(18.89)	(135.72)	(70.38)
Percent of population under 18 years of age	0.76**	0.92**	0.99**	0.99**
	(11.27)	(21.13)	(83.15)	(106.45)
Percent of population that is White	0.72**	0.89**	0.95**	0.97**
	(9.29)	(15.57)	(23.05)	(38.73)
B. Measures of Regulation				
Approvals required for projects with no zoning change	0.66**	0.82**	0.93**	0.96**
	(7.22)	(9.55)	(15.39)	(25.35)
Approvals required for projects with a zoning change	0.62**	0.82**	0.93**	0.95**
	(6.35)	(9.67)	(16.64)	(21.59)
Development caps	0.28	0.63**	0.73**	0.77**
	(1.93)	(4.17)	(4.49)	(4.33)
Density restrictions	0.44**	0.73**	0.77**	0.82**
	(3.51)	(6.05)	(5.42)	(5.66)
C. Permits Issued				
Single-family housing permits issued 1990-2006 / (Housing stock in 1990)	0.30*	0.59**	0.89**	0.92**
	(2.16)	(3.69)	(10.89)	(12.09)
All permits issued 1990-2006 / (Housing stock in 1990)	0.38**	0.64**	0.84**	0.87**
	(2.83)	(4.29)	(7.58)	(8.02)

Notes: Asymptotic t-ratios are in parenthesis.
* indicates significance at the 0.05 level and ** indicates significance at the 0.01 level.

First Order Spatial Autoregressive Models

The basic empirical model of spatial autocorrelation takes the following form:

$$y = \rho^* W^* y + \varepsilon ,$$

Where W is a matrix of spatial weights, standardized so that its rows sum to one, and y is a quantitative variable, e.g., one of the regulation measures described above (expressed in deviations from the mean to eliminate the constant term in the model). The ρ term, a simple correlation coefficient, is estimated using maximum likelihood methods. We test this spatial autoregressive model using four different spatial weights matrixes: a contiguity matrix, in which the elements of the weight matrix, W_{ij}, have a value of one one if $city_i$ and $city_j$ share a border and zero otherwise, and three different inverse distance matrices. The elements of each inverse distance matrix are $W_{ij} = 1/d_{ij}$, for $d_{ij} \leq d^*$, and $d_{ij} = 0$ for $d_{ij} > d^*$. d_{ij} is the distance between $city_i$ and $city_j$, and d* is the distance cut-off point. In the simple autocorrelation tests, we consider cut-off points at 20, 30 and 40 kilometers, as illustrated in Figure 1. Beyond the cut-off point, cities i and j do not influence each other.

Table 7 presents spatial autocorrelation measures for the 76 cities in the sample, using these four spatial weight matrices. All of the demographic variables are highly positively spatially correlated – cities are similar to their neighbors – and increasingly so as the definition of neighbor becomes broader. The regulatory variables are also consistently serially correlated over space, although much less so than the demographic variables, and not very highly when only considering immediate neighbors. The number of development caps and density restrictions are less spatially correlated than the number of reviews needed for project approval or zoning changes. Permits for single-family homes, and all residential permits combined are also less spatially correlated than the demographic variables, especially at low distance thresholds.

It is striking that all the correlation coefficients reported in Table 7 are positive, and all coefficients are statistically significant at the 0.05 level. Indeed, of the 44 correlation coefficients reported in Table 7, 42 are significant at the 0.01 level. Demographic characteristics and local regulations are significantly and positively correlated over space, and the propensity of cities to issue building permits is also highly correlated.

Based on the above measures of spatial autocorrelation, we use the 30 km inverse distance weights matrix for the remainder of the analysis. While the 'right' spatial neighborhood is always difficult to define, considering a 30 km boundary is appropriate for the influence on regulation. Cities are influenced by more than just those cities they border, or those very close by. Restricting the distance boundary to 30 km also simplifies the analysis.

OLS and Spatial Autoregressive (SAR) Models

From Table 7, it is clear that a positive spatial autocorrelation exists between regulations and permits. But does this depend simply on the spatial autocorrelation of demographic variables? In order to test this, we compare simple ordinary least squares models of the determinants of regulation with results obtained using the SAR model, which includes a spatial lag of the dependent variable. SAR models take the form:

$$y = \rho * W * y + X * \beta + \varepsilon \, ,$$

Where again, the W matrix is a spatial weight matrix and the ρ term is the spatial correlation coefficient. Note that in this formulation, the spatial autocorrelation is conditional on the matrix of explanatory variables in X. As with other empirical work on regulation, we assume that city demographic characteristics are not endogenous in these models; the demographic information refers to conditions seven years earlier than the regulatory data, and is thus relatively unaffected by the regulation.

Table 8 reports the results from the OLS models relating demographic characteristics of the cities to the regulations they have adopted and the building permits they have issued. There is essentially no impact of demographic characteristics on the approvals process for new housing projects or for zoning changes. However, several demographic characteristics (the percent of residents with a college education, the percent of the residents under 18 years of age, and the percent of residents that are White), have a significant impact on the number of development caps enacted by a jurisdiction. The percent of residents that are White is positively associated with the level of density restrictions. Overall, the influence of demographic characteristics on the regulations is not large. Several demographic variables - the percent of adults with a college education, the percent of dwellings that are owner-occupied, and the percent of residents that are White – have a weakly significant impact on the number of residential building permits issued by a jurisdiction for single-family housing between 1990 and 2006, measured as a fraction of the total residential housing stock in 1990.

Table 8
OLS Models of the Determinants of Regulatory Stringency

	Project	**Zoning**	**Caps**	**Density**	**SFH**	**All**
Intercept	-0.72	-12.82	-5.63	-12.56	0.87	0.85
	(-0.04)	(-0.68)	(-0.62)	(-1.24)	(0.40)	(0.29)
Log (Median household income)	0.64	1.97	0.46	1.20	-0.10	-0.07
	(0.37)	(1.03)	(0.52)	(1.16)	(-0.45)	(-0.23)
Percent of adult residents with a college degree	2.23	-2.88	-5.31**	-3.50	-0.86**	-1.05
	(0.45)	(-0.46)	(-2.37)	(-1.16)	(-2.61)	(-1.42)
Percent of dwellings that are owner-occupied	-2.85	-3.78	-2.67	-1.20	0.53	0.46
	(-0.88)	(-1.03)	(-1.53)	(-0.69)	(1.07)	(0.86)
Percent of population under 18 years of age	-3.15	-3.71	7.40**	3.55	0.15	-0.31
	(-0.42)	(-0.47)	(2.01)	(0.93)	(0.19)	(-0.30)
Percent of population that is White	1.21	1.13	3.16**	2.28**	0.22*	0.15
	(0.93)	(0.82)	(3.76)	(2.99)	(1.71)	(0.87)
R-squared	0.08	0.04	0.26	0.12	0.29	0.19
F	1.21	0.65	3.67**	2.86**	7.32**	3.93**

Notes: T-ratios are in parenthesis, generated using White robust standard errors.
* indicates significance at the 0.10 level and ** indicates significance at the 0.05 level.

The SAR models reported in Table 9 include a spatial lag of the dependent variable, making it possible to test the effect of the level of regulation in neighboring cities on the regulation adopted in any city, while controlling for the demographic characteristics of that place. The estimate of ρ, the spatial lag, is statistically significant for the models of development caps, density restrictions, single-family housing permits and all permits. It indicates, for example, that the number of development caps enacted by neighboring cities positively influences the number of development caps in any city, controlling for the demographic characteristics of that city. The spatial correlation is negative for density restrictions, which is consistent with the conventional wisdom that cities restrict density within their own jurisdiction in reaction to the absence of density control in neighboring cities.

Each of the SAR models reported in Table 9 is highly significant, as indicated by their associated χ^2 values. It is tempting to interpret the autocorrelation parameters, significantly different from zero in four of the models, as evidence of strategic interaction among jurisdictions. Interpreted literally, the results in Table 9 state that cities are likely to take neighbors' land-use regulation into account when adopting their own rules. Indeed, in Brueckner's (1998) analysis, a test for strategic interaction among local governments is merely a test of the significance of the spatial lag term. But these SAR models suffer from a potentially spurious indication of spatial influence. It is certainly possible that the significant spatial association observed arises merely from the spatial correlation in demographic variables that determine regulatory policies and permitting outcomes. Thus, although a city's proclivity to restrict density or impose development caps is associated with that of its neighbors, this may arise from the similarity in the demographic characteristics of neighboring cities rather than from some strategic interaction or reaction. We test this below.

Table 9
SAR Models of the Determinants of Regulatory Stringency

	Project	**Zoning**	**Caps**	**Density**	**SFH**	**All**
Intercept	-1.35	-12.62	-6.74	-10.47	0.64	0.63
	(-0.08)	(-0.65)	(-0.72)	(-1.02)	(0.46)	(0.35)
Log (Median household income)	0.83	2.12	0.58	1.05	-0.07	-0.04
	(0.48)	(1.08)	(0.61)	(1.01)	(-0.48)	(-0.23)
Percent of adult residents with a college degree	2.28	-2.90	-4.62*	-3.16	-0.75*	-0.99*
	(0.44)	(-0.49)	(-1.64)	(-1.02)	(-1.82)	(-1.83)
Percent of dwellings that are owner-occupied	-3.21	-4.06	-2.26	-1.08	0.54**	0.46
	(-0.98)	(-1.09)	(-1.28)	(-0.55)	(2.06)	(1.34)
Percent of population under 18 years of age	-2.93	-4.07	5.90	4.21	-0.31	-0.67
	(-0.43)	(-0.53)	(1.58)	(1.03)	(-0.57)	(-0.94)
Percent of population that is White	1.15	1.10	2.46**	2.18**	0.12	0.06
	(0.79)	(0.67)	(3.02)	(2.54)	(1.04)	(0.42)
ρ	-0.26	-0.27	0.36**	-0.41*	0.57**	0.39**
	(-1.07)	(-1.10)	(2.00)	(-1.79)	(3.95)	(2.09)
χ^2	263.38	282.46	170.5	185.9	118.76	79.4

Notes: Asymptotic t-ratios are in parenthesis.
* indicates significance at the 0.10 level and ** indicates significance at the 0.05 level.

Spatial Durbin Models

In order to separate the influence of the regulations adopted by neighbors from the fact that cities are demographically similar over space, we estimate a series of spatial Durbin models.[5] By including spatial lags of demographic characteristics of neighboring cities on the right hand side of the regression model, spatial Durbin models test whether the demographic composition of neighbors influence a city's decision to adopt regulations. More importantly, however, the significance of the spatial lag of regulation, ρ, now represents a test of whether cities recognize and react to their neighbors' regulatory decisions, controlling for the demographic similarity of cities across space.

The spatial Durbin models take the form:

$$y = \rho * W * y + X * \beta_1 + W * X * \beta_2 + \varepsilon ,$$

Where y, ρ, W and X are the same as before, but now there is an additional matrix X of independent variables that is lagged over space with the weight matrix W. The vector of coefficients β_2 measures the influence of demographic characteristics of neighboring cities on the regulatory outcomes observed in a city.

Table 10 reports the results of spatial Durbin models that include all the independent variables considered previously and the spatial lag of the most important right hand side

[5] See Brasington and Hite (2005) for a clear exposition of the spatial Durbin model and an application to housing markets.

variables from the SAR model (the percent of residents with a college education, the percent dwellings that are owner-occupied, and the percent of residents that are White). All the models are significant as indicated by the log- likelihood ratios and their associated χ^2. Some of the independent variables in the models are statistically significant at conventional levels, including some of the spatial lags of demographic characteristics.

However, the spatial lags of development caps, density restrictions and the permits for single-family housing, significant in the SAR models, are insignificantly different from zero when controlling for the demographic characteristics of neighboring cities. Thus, we cannot reject the hypothesis that there is no association between cities' regulatory decisions and those of their neighbors. Similarly, in the models for the number of approvals or reviews needed for development projects and zoning changes, and all residential permits issued from 1990-2006, we are unable to reject the null hypothesis for ρ. There is apparently no interaction among local governments' regulatory decisions.

To test the robustness of the relationship, we estimate a series of parsimonious spatial Durbin models, which only include the three variables that are most significant in the SAR models and their spatial lag. Table 11 reports these results. The significance of ρ for models of regulatory variables and permits issued does not change under this specification, indicating that it is not possible to distinguish the spatial autocorrelation in regulations enacted by cities from the spatial autocorrelation in their demographic characteristics.

Table 10
Spatial Durbin Models of the Determinants of Regulatory Stringency

	Project	Zoning	Caps	Density	SFH	All
Intercept	-11.24	-20.00	-14.05	-6.70	0.00	-0.77
	(-0.61)	(-0.95)	(-1.41)	(-0.60)	(0.00)	(-0.44)
Log (Median household income)	1.50	2.82	1.14	0.69	-0.07	-0.01
	(0.81)	(1.34)	(1.14)	(0.62)	(-0.49)	(-0.03)
Percent of adult residents with a college degree	2.34	-2.85	-4.89*	-3.43	-0.78**	-1.00**
	(0.45)	(-0.49)	(-1.75)	(-1.10)	(-2.02)	(-2.05)
Percent of dwellings that are owner-occupied	-3.51	-4.45	-2.78	-0.88	0.53**	0.44
	(-1.08)	(-1.21)	(-1.58)	(-0.45)	(2.17)	(1.42)
Percent of population under 18 years of age	0.73	0.83	2.46**	2.63**	0.09	0.01
	(0.41)	(0.41)	(2.53)	(2.46)	(0.69)	(0.06)
Percent of population that is White	-6.08	-5.56	4.55	5.11	-0.42	-1.03
	(-0.85)	(-0.69)	(1.18)	(1.19)	(-0.78)	(-1.53)
W*(Percent of adult residents with a college degree)	-4.32	-2.06	-3.27	2.92	-1.02*	-1.56**
	(-0.70)	(-0.30)	(-0.92)	(0.80)	(-1.92)	(-2.48)
W*(Percent of Dwellings that are owner-occupied)	3.18	-3.02	0.51	-0.51	1.81**	2.58**
	(0.55)	(-0.46)	(0.17)	(-0.15)	(3.72)	(4.49)
W*(Percent of population that is White)	3.84	4.47	3.54*	-1.18	-0.28	-0.12
	(1.29)	(1.32)	(1.93)	(-0.65)	(-1.25)	(-0.42)
ρ	-0.26	-0.30	0.17	-0.37	0.10	-0.13
	(-1.04)	(-1.23)	(0.81)	(-1.52)	(0.45)	(-0.56)
χ^2	261.23	280.57	166.74	185.07	134.08	98.88

Notes: Asymptotic t-ratios are in parenthesis.
* indicates significance at the 0.10 level and ** indicates significance at the 0.05 level.

Table 11
Limited Spatial Durbin Models of the Determinants of Regulatory Stringency

	Project	Zoning	Caps	Density	SFH	All
Intercept	3.24	7.36	-2.78	0.20	-0.70**	-0.88**
	(0.78)	(1.52)	(-1.27)	(0.08)	(-2.25)	(-2.31)
Percent of adult residents with a college degree	6.40*	3.55	-3.66*	-3.19	-0.83**	-0.81**
	(1.85)	(0.90)	(-1.95)	(-1.52)	(-3.19)	(-2.46)
Percent of dwellings that are owner-occupied	-3.09*	-2.30	-0.31	1.16	0.35**	0.20
	(-1.64)	(-1.07)	(-0.30)	(1.01)	(2.47)	(1.09)
Percent of population that is White	1.14	1.28	2.20**	2.38**	0.11	0.07
	(0.66)	(0.65)	(2.30)	(2.26)	(0.88)	(0.44)
W*(Percent of adult residents with a college degree)	-2.04	1.62	-2.25	3.12)	-1.10**	-1.54**
	(-0.35)	(0.25)	(-0.66)	(0.91)	(-2.15)	(-2.53)
W*(Percent of Dwellings that are owner-occupied)	2.41	-3.33	1.79	0.69	1.76**	2.46**
	(0.43)	(-0.52)	(0.58)	(0.20)	(3.62)	(4.26)
W*(Percent of population that is White)	2.83	3.03	3.21*	-1.03	-0.28	-0.19
	(0.99)	(0.93)	(1.80)	(-0.58)	(-1.32)	(-0.69)
ρ	-0.26	-0.30	0.23	-0.38	0.05	-0.21
	(-1.04)	(-1.23)	(1.07)	(-1.56)	(0.23)	(-0.89)
χ^2	262.48	282.65	169.60	187.05	133.17	96.61

Notes: t-ratios are in parenthesis, * indicates significance at the 0.10 level and ** indicates significance at the 0.05 level.

V. Conclusion

This paper analyzes the geographical pattern of land-use regulation and permitting policies which are adopted independently by local governments in the United States in an autarchic fashion. We exploit a unique body of data on the regulations imposed by local governments in the San Francisco Bay Area, one of the most heavily regulated metropolitan landscapes in the country and one with historically high housing prices. We analyze decisions made by local governments about the kinds of reviews required to obtain permits for new residential construction. We also analyze decisions about the reviews required by local governments for a change in zoning. Beyond these, we analyze, the number and type of development caps enacted by local governments as well as the lot-size restrictions enacted. Finally, we analyze the geographical distribution of permits issued by local governments for the construction of single-family and all housing.

Our analysis documents the high degree of similarity among these regulations over space. Maps suggest that cities that adopt more restrictive regulations tend to be close to other cities that have adopted similar policies. More precise measures confirm that regulations are spatially autocorrelated and that these correlations are highly statistically significant. Measures of the demographic characteristics of cities, presumably the determinants of local regulatory policy, are highly correlated over space as well. In our quantitative analysis, we seek to determine whether the observed autocorrelation of cities' decisions regarding land-use regulation across space represents strategic interaction or whether it arises simply from the strong demographic similarity of neighboring cities.

Previous research based on SAR models has found that the number of growth control ordinances in a city is positively influenced by the number of growth control ordinances in its neighboring cities. We present analogous tests, clarifying the definition of neighboring cities and expanding the analysis to several regulatory categories: reviews needed for project and zoning change approval, development caps, and density restrictions. We find that for some categories (project and zoning change approvals or reviews), there is no significant impact of a spatial lag term, for others (development caps) there is a positive impact, and still others (density restrictions), there is a negative impact. It is tempting to interpret the results of these models as evidence of recognition or interaction between cities' regulatory policy.

However, the interpretation of these findings based on SAR models is confounded by the strong spatial autocorrelation of the demographic characteristics of cities. We test explicitly for the possibility that the observed impacts of regulatory decisions by a city's neighbors are spurious, arising from demographic similarity of cities across space. We thus estimate statistical models (spatial Durbin models) that control for the demographic characteristics of neighboring cities. The impact of neighboring cities' regulatory decisions is never statistically significant when controlling for their demographic characteristics. These models do not "disprove" interaction or recognition of regulatory decisions by neighboring cities, but they provide no evidence of any form of interaction. These results also provide a simple alternative explanation for the so-called "strategic interaction" of local regulation describe elsewhere.

The analysis suggests several directions for empirical research on the spatial aspects of land-use regulation. First, it would be useful to compare results from similar models in different metropolitan areas in order to understand the importance of region-specific factors on the distribution of regulatory decisions across space. Second, a method for incorporating the influence of county level land-use regulation of unincorporated areas is necessary to complete the understanding of local land-use regulation over space in metropolitan areas. Finally, it seems that cross-sectional analysis will not be sufficient to show evidence of interaction, and it is necessary to investigate explicitly the dynamics of regulation and regulatory interaction.

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