Subcentering and Commuting: Evidence from the San Francisco Bay Area, 1980-1990

Robert Cervero
with research assistance by Kang-Li Wu

Working Paper
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The University of California Transportation Center

University of California
Berkeley, CA 94720

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1. RESEARCH QUESTIONS

The dominant spatial trend in U.S. metropolitan areas during the fast-growing 1980s was decentralization of employment. Between 1980 and 1990, the number of jobs in U.S. metropolitan areas increased by 49.2 percent outside of central cities compared to 13.1 percent within them. In all, two-thirds of all metropolitan job growth occurred outside of central cities during the 1980s (Hughes, 1992).

The effects of employment decentralization on the journey-to-work has sparked a lively, and at times contentious, policy debate. Some argue that job dispersion economizes on commuting. Using data from the 1980 census and 1985 American Housing Survey, Gordon et al. (1991, p. 419) found that average commute times fell for 18 of the 20 largest U.S. metropolitan areas during the first half of the 1980s, concluding that "polycentric or dispersed metropolitan structures are favorable to short commutes". Gordon and Richardson (1995, p. 355) more recently found average commute speeds to have increased between 1983 and 1990 in virtually every size class of metropolitan area, concluding that spread-out development reduces traffic congestion "by taking advantage of agglomerative economies that are apparently available at comparatively low densities and throughout each metropolitan area". Gordon and Richardson's work, however, stands in marked contrast to the findings of Rosetti and Eversole (1993) who show that mean commute times increased during the 1980s in 35 of the 39 U.S. metropolitan areas with 1990 populations over one million.

Part of the explanation for conflicting findings could be the use statistical means from aggregate, metropolitan-wide data that are obtained from different national surveys. However, neither are findings from more disaggregate studies fully consistent. Wachs et al. (1993) traced changes in journeys-to-work for a panel of over 8,000 hospital workers throughout southern California, finding that the average distance traveled decreased slightly from 10.0 miles in 1984 to 9.7 miles in 1990. A recent study of commuting in the greater Washington, D.C. area, however, found average work-to-home lengths rose from 6.6 miles in 1968 to 8.2 miles in 1988, prompting the authors to conclude that "the effect of decentralization is to increase trip lengths" (Levinson and Kumar, 1994, p. 328). And in a study disaggregate study of 1977 intrametropolitan commuting in greater Baltimore, Dubin (1991) found workers at peripheral employment centers traveled slightly longer distances than their counterparts with downtown jobs, though their average commuting times were shorter. Studies of the effects of office relocations from downtowns to suburbs on the commuting habits of individual employees perhaps provide the most disaggregate, "controlled" studies available. Most (Wabe, 1967; Daniels, 1972, 1981 O'Connor, 1980; Ley, 1985; Bell, 1991; Cervero and Landis, 1992) have shown few changes in average commuting distances and durations after firms relocated to the suburbs, though in all cases there were significant shifts toward drive-alone commuting.

To a significant degree, the research literature has been fairly silent on the question of how decentralization effects mode choice and average vehicle occupancies, concentrating on spatial (e.g., journey distance) and temporal (e.g., journey duration) impacts instead. Yet rising public concerns over environmental quality and "excessive automobility" (Dittmar, 1995) suggest we should be studying the effects of decentralization not only on commute distances and speeds, but on the question of resource efficiency (e.g., average vehicle occupancy levels and modal distributions) as well. Examining shifts in measures like vehicle miles traveled (VMT) per worker, for example, allows both the spatial (e.g., distance) and modal (e.g., vehicle occupancy) implications of commuting trends to be examined.

This paper seeks to broaden our perspective into the transportation and environmental implications of suburban employment growth during the 1980s using data for the San Francisco Bay Area. Our work is distinguished from previous studies in several respects. Since job decentralization was the dominant spatial trend of the 1980s, we concentrate on shifts in commuting to employment centers (that meet minimum size and density thresholds) as opposed to the region at large. Notably, we focus on how the trend toward polycentric development and subcentering, a trend that characterizes virtually every U.S. metropolitan area (see Gordon, et al., 1986; Pivo, 1990; Chinitz, 1991), has effected commuting patterns. Also, we examine the spatial, temporal, and modal dimensions of commuting. Notably, trends in VMT per employee are examined, and sensitivity tests are used to infer the degree to which changes are attributable to shifts in commute distances versus modal choices and occupancy levels. We hypothesize that employment subcentering in the San Francisco Bay Area has increased VMT per employee, attributable mainly to a lengthening of commutes and secondarily to reduced transit and ridesharing market shares (which in turn has lowered average vehicle occupancies).

2. RESEARCH APPROACH

The Consolidated Statistical Metropolitan Area (CMSA) of San Francisco-Oakland-San Jose, more commonly called the Bay Area, was chosen for carrying out this research. This was partly because the Bay Area experienced one of the fastest rates of suburban employment growth in country the 1980s (Cervero and Wu, 1997), witnessing the emergence of several large-scale job centers, like the Silicon Valley, during this period. The availability of reliable employment and journey-to-work data, disaggregated at the census tract level for both 1980 and 1990, also prompted us to choose the Bay Area suitable as a case study.[1]

Defining Employment Centers

The research proceeded over several steps. First, employment centers that existed in 1990 were defined based on size and density criteria. In all, 22 Bay Area employment centers (ECs), made up of contiguous census tracts, were identified in 1990. We then compiled employment size and density data for the same 22 ECs in 1980, making adjustments to the census boundaries of the ECs to account for less job concentration (mainly in the suburbs) at the time. This allowed us to compare and map changes in the size, densities, and occupational compositions of the same 22 ECs from 1980 to 1990. Also, shifts were examined among four hierarchical classes of ECs.

Commuting Statistics

Next, 1980 and 1990 journey-to-work statistics were generated for the 22 ECs and the four EC classes. Five "output" measures of commuting impact were examined: (1) average one-way durations; (2) average one-way distances; (3) modal splits; (4) average vehicle occupancy levels; and (4) VMT per employee. Journey-to-work census records were tied to census tract of employment and then matched to ECs in order to disaggregate these statistics.

Information on average commute durations, vehicle occupancies, and modal splits were based on what respondents recorded in census questionnaires based on the "usual" journey-to-work the prior week;[2] though these are estimates, we can safely assume any biases were of a similar magnitude in 1980 as 1990, allowing changes during the 1980s to be reliably measured. Average commute distances were calculated based on highway and transit network distances using the MINI-UTP software program and "skimming" the 1980 and 1990 regional networks. (In 1990, the Bay Area's transportation network, used in long-range forecasting and planning, consisted of over 13,000 nodes and 15,000 links.) This approach assumes commuters will chose the shortest route to work; while not perfect, it likely more closely represents actual commute distances than centroid-to-centroid straightline measures. For each EC, the total number of commute trips made from any of the region's 1,382 census tracts to that EC constituted an origin-destination (O-D) pair. All commutes for each O-D pair were loaded onto the shortest route of the network. Summing over all trip interchanges destined to an EC produced a commute distance total. Dividing this by the EC's employment total yielded an average "network" commute distance for that EC.

Calculating VMT per employee, using equation 1, for each EC required assumptions on average vehicle occupancy levels. For each O-D pair linked to a particular EC, the total number of trips was stratified by mode. Modal volumes were then adjusted for average work-trip occupancy levels (obtained either from the census data or 1990-1991 Bay Area travel survey records) to convert "person trips" to "vehicle trips". For example, 35 bus transit trips from a residential tract to an EC represents a single vehicle trip if the average occupancy level for a bus commute was 35 employees. (Walk and bicycle trips constituted zero vehicle trips.) Multiplying vehicle trips by network distance for each O-D pair, and then summing over all O-D pairs and dividing by total employment yielded an estimated commute-trip VMT per employee for each employment center j.

$$\text{VMT/employee}_j = [\sum_i \sum_k (T^k_{ij}/O^k) D^k_{ij}]/E_j \quad (1)$$

where:
T = total person work trips
D = network distance
E = employment
O = average occupancy level[3]
I = residential census tract index (I = 1,2,......,1,382)
j = employment center index (j = 1, 2,...,22)
k = commute mode index [drive-alone, vehicle pool (1-10 or 12 occupants), bus transit and cable car (35 occupants), light rail (70 occupants), and heavy and commuter rail (220 occupants)].

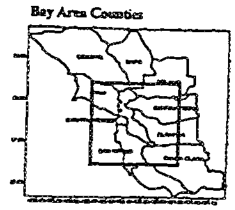
3. BAY AREA EMPLOYMENT CENTERS: 1980 & 1990

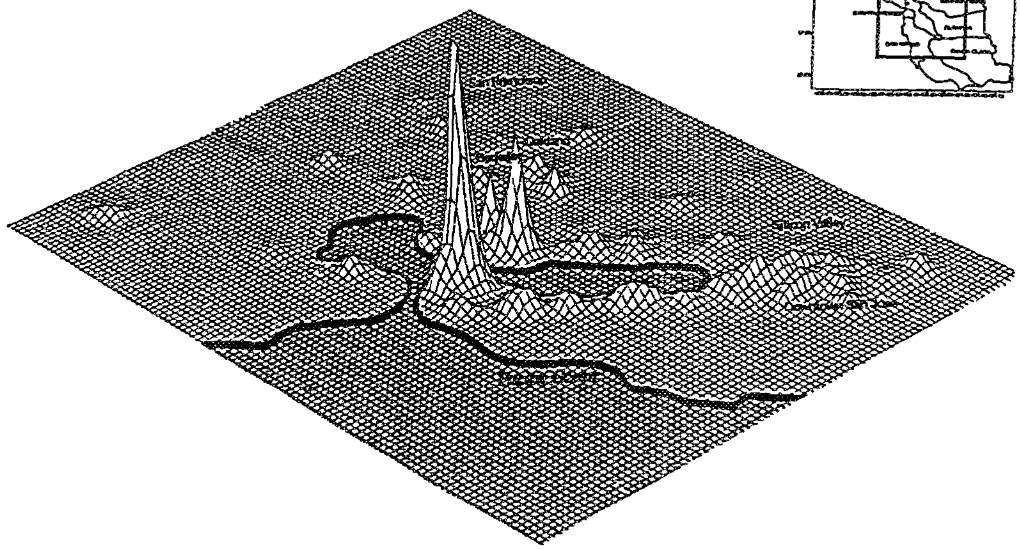
Employment density gradients have traditionally been used to define ECs (Gordon et al., 1986; MacDonald, 1987; McDonald and Prather, 1994; Giuliano and Small, 1991; Cervero and Wu, 1997). Figures 1 and 2 portray employment densities in the Bay Area in both 1980 and 1990. The three-dimensional surface model plot shows downtown San Francisco was the largest and densest EC during the 1980s, with the East Bay downtowns in Oakland, Berkeley, and Emeryville forming second-tier centers. Most remaining ECs had comparably moderate densities in 1980, but by 1990, the Silicon Valley, one of the world's premier high-technology agglomerations, had emerged as a significant secondary center. Both figures show that employment in the Silicon Valley not only intensified during the 1980s, but the Valley's spatial extent had appreciably enlarged by 1990 as well. With the emergence of more and denser ECs in the Peninsula (south of San Francisco) and the East Bay, by 1990 the Bay Area had taken on a decidedly more polycentric settlement pattern, one with some degree of EC hierarchy.

1990 Employment Centers

In earlier work (see Cervero and Wu, 1997), we identified 22 distinct Bay Area ECs in 1990, each comprised of a contiguous set of census tracts that met two criteria: (1) 7 or more workers per gross acre; and (2) 9,500 or more employees. For purposes of comparing 1980-1990 trends in commuting in this study, the ECs were grouped into four classes, mainly on the basis of 1990 EC densities, as reflected in Figure 1: (1) downtown San Francisco; (2) Oakland, Berkeley, and Emeryville (i.e., the East Bay core); (3) Silicon Valley and downtown San Jose, in

Three-Dimensional Employment Density Model,
San Francisco Bay Area, 1980





Three-Dimensional Employment Density Model,
San Francisco Bay Area, 1990

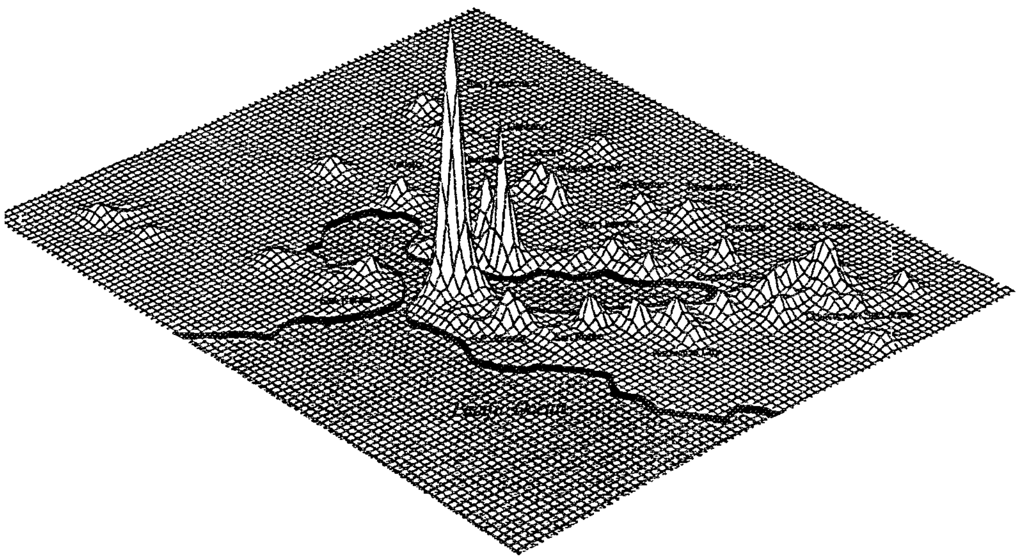


Figure 1. Employment Density Models of the San Francisco Bay Area, 1980 and 1990

Spatial Distribution of Employment Density, San Francisco Bay Area, 1980

Spatial Distribution of Employment Density, San Francisco Bay Area, 1990

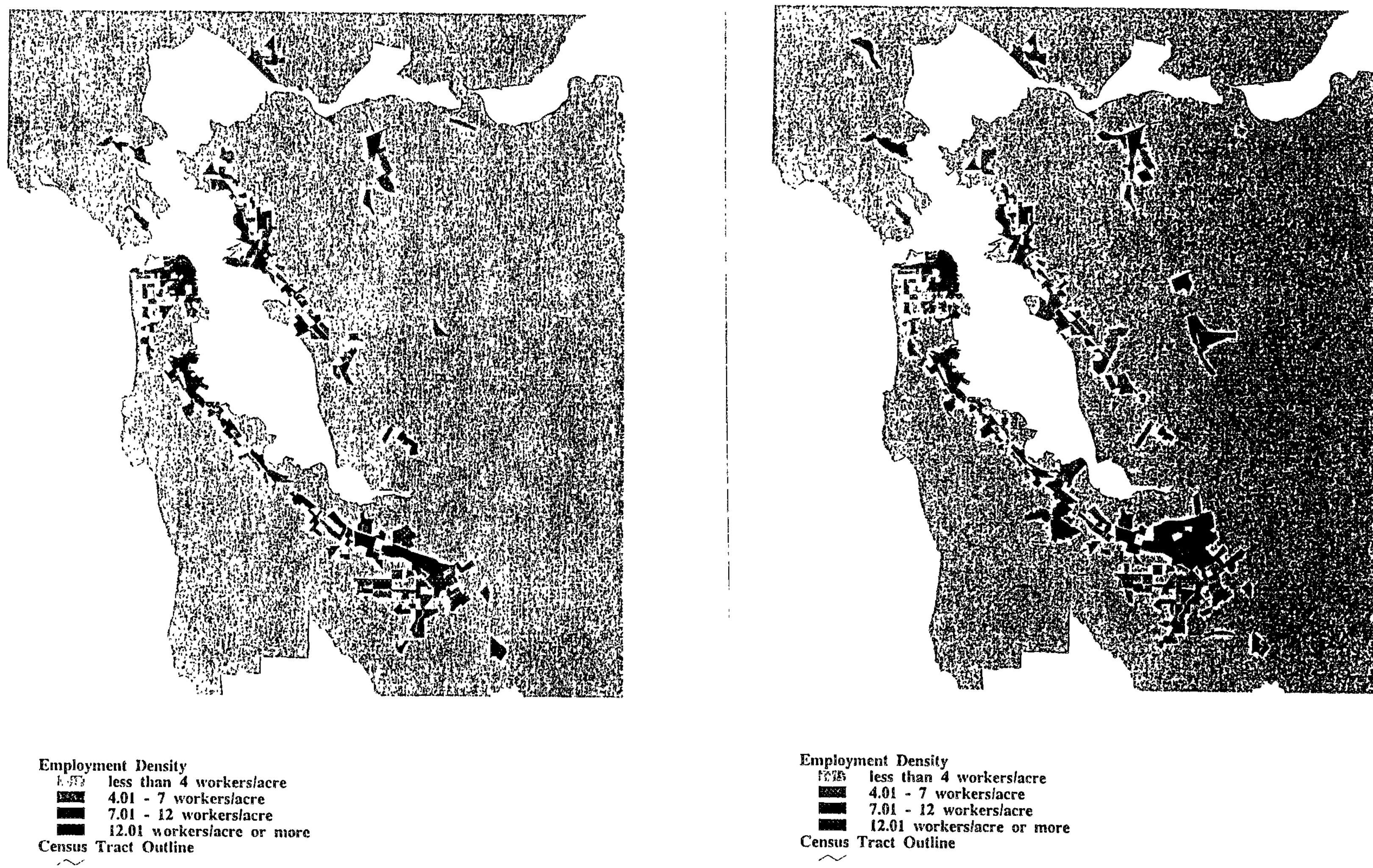


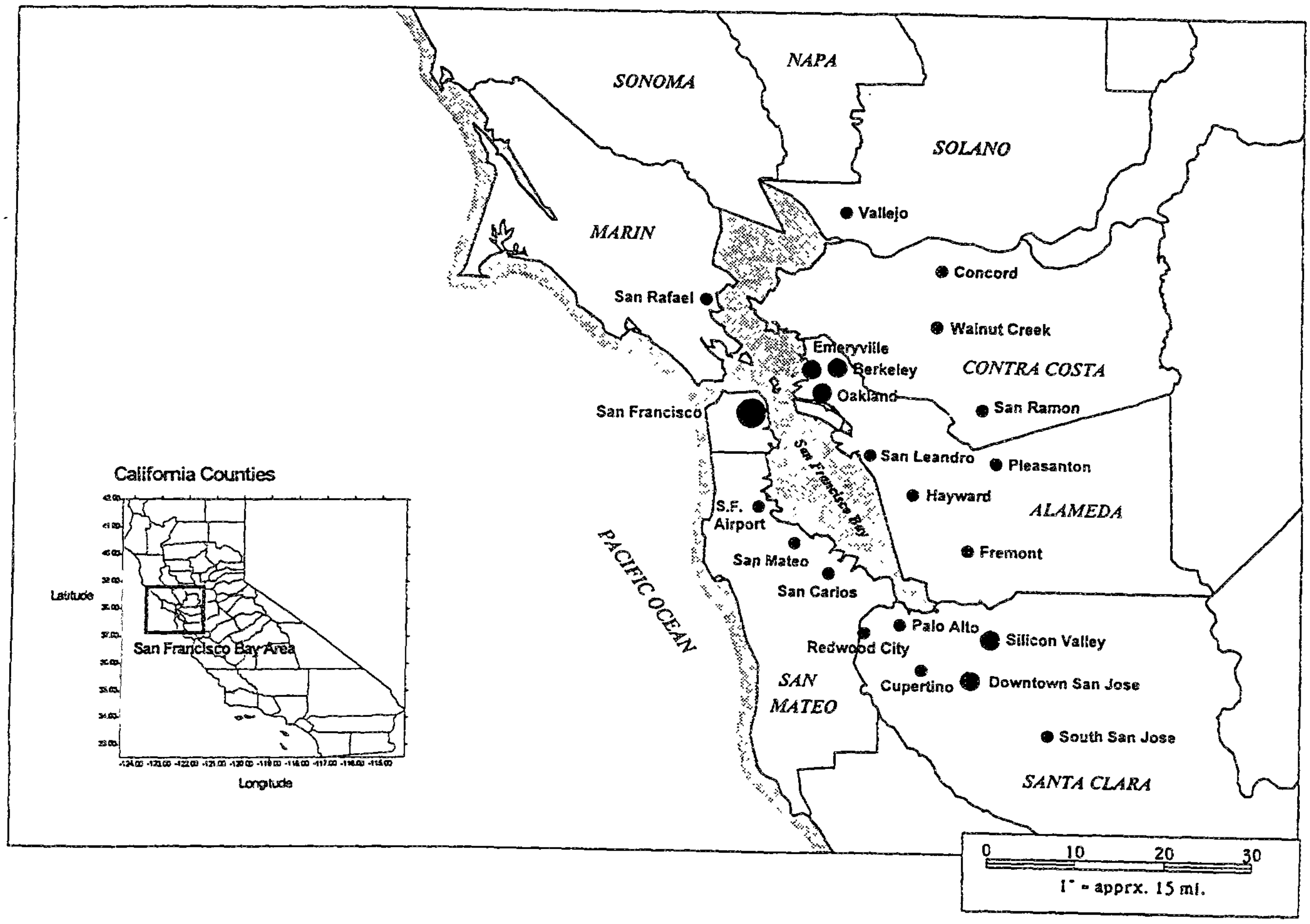
Figure 2. Spatial Distributions of Employment Densities, San Francisco Bay Area, 1980 and 1990

the South Bay; and (4) the remaining 16 ECs, what we will call suburban employment centers. (See Map 1.) San Francisco, Oakland, Berkeley, and Emeryville are all fairly mature urban centers, geographically situated in the center of the region. Silicon Valley and central San Jose in the South Bay are comparatively new, fast-growing ECs, with economic bases primarily in the electronic, biotechnology, software development, computer and semiconductor manufacturing, and business services sectors. The region's suburban ECs are smaller (most under 40,000 employees in 1990[4]), average lower densities (7-10 workers per gross acre in 1990), and orbit the larger urban ECs. Several suburban centers stood out as growth magnets in the 1980s. The San Francisco Airport area and San Mateo, in the Peninsula, both added an impressive amount of office, warehousing, and light industrial space during the 1980s. By far, the two fastest growing Bay Area suburban ECs were San Ramon and Pleasanton, both of whose employment bases increased more than 8 times during the 1980s. San Ramon and Pleasanton absorbed thousands of white-collar and back-office jobs relocated from downtown San Francisco and, to a lesser extent, Oakland, Berkeley, and the South Bay. Many of these jobs ended up in large-scale, master-planned business parks, the two most prominent being the 585-acre Bishop Ranch in San Ramon and the nearby 860-acre Hacienda Business Park in Pleasanton (Cervero, 1986; Cervero, 1989a).

Comparisons to 1980

To draw 1980-1990 comparisons, the same 22 ECs defined using 1990 employment data were identified as of 1980. Because most ECs had fewer workers and spatially were not as expansive, they tended to encompass fewer census tracts in 1980. In setting the boundaries of the 22 ECs for 1980, minimum employment size and density thresholds for contiguous tracts were lowered to 8,600 workers and 4.5 employees per acre, respectively; the two exceptions were San Ramon and Pleasanton (both of which were predominantly bedroom communities in 1980), wherein EC criteria were relaxed altogether so as to retain them as cases.

Table 1 presents 1980-1990 changes in employment totals and densities among the 22 centers, as well as employment breakdowns across four dominant occupational classes. Employment in the 22 ECs grew, on average (unweighted), by 23.6 percent; only two ECs (San Leandro and Palo Alto) lost employment, though in Palo Alto's case this was largely an anomaly



Map 1. The Bay Area's 22 Employment Centers

Table 1. Bay Area Employment Center Sizes, Densities, and Occupational Breakdowns, 1980 and 1990

Employment Center	EMPLOYMENT: Total 1980	Total 1990	Total % change	Workers per Gross Acre 1980	Workers per Gross Acre 1990	Workers per Gross Acre % change	OCCUPATIONS: % Managerial, Executive & Professional 1980	1990	% pt. change	% Administrative, Sales & Clerical 1980	1990	% pt. change	% Service Occupations 1980	1990	% pt. change	% Precision Production & Operators 1980	1990	% pt. change
San Francisco	426,212	462,731	8.6%	50.22	65.45	30.34%	35.8%	40.7%	4.9%	36.8%	31.4%	-5.4%	11.5%	9.7%	-1.9%	15.2%	10.6%	-4.6%
Oakland	84,054	99,042	17.8%	27.68	34.06	23.15%	34.3%	37.9%	3.6%	35.2%	28.1%	-7.1%	11.4%	7.9%	-3.6%	18.3%	13.1%	-5.2%
Berkeley	40,275	46,866	16.4%	13.16	14.06	6.8%	50.2%	55.2%	5.1%	28.6%	24.9%	-3.7%	11.8%	9.2%	-2.5%	8.4%	6.2%	-2.2%
Silicon Valley	181,871	263,840	45.2%	25.16	28.16	11.9%	33.1%	43.5%	10.4%	24.7%	24.5%	-0.2%	5.7%	5.2%	-0.5%	35.7%	19.3%	-16.4%
Downtown San Jose	53,766	77,256	43.7%	10.52	14.03	33.4%	34.5%	40.6%	6.2%	31.1%	29.6%	-1.5%	12.4%	9.2%	-3.2%	20.9%	12.1%	-8.8%
Emeryville	28,387	32,380	14.1%	8.69	8.88	2.2%	28.7%	40.6%	11.9%	24.7%	25.3%	0.7%	8.6%	9.0%	0.3%	37.1%	16.8%	-20.3%
San Leandro	23,037	22,720	-1.4%	7.61	8.92	17.2%	17.9%	24.5%	6.6%	27.9%	31.4%	3.5%	6.8%	6.6%	-0.2%	46.5%	24.0%	-22.5%
Hayward	17,320	27,426	58.3%	12.73	14.08	10.6%	28.6%	27.7%	-0.9%	41.2%	33.9%	-7.3%	10.0%	8.5%	-1.5%	19.5%	16.9%	-2.6%
S.F. Airport	65,817	81,772	24.2%	9.53	14.80	55.3%	22.3%	26.8%	4.5%	32.0%	30.0%	-2.0%	10.9%	12.0%	1.2%	33.9%	19.0%	-14.9%
San Mateo	23,780	25,548	7.4%	16.28	16.15	-0.8%	31.5%	33.8%	2.3%	40.7%	39.6%	-1.2%	13.0%	10.3%	-2.7%	13.4%	8.2%	-5.2%
San Carlos	31,495	36,555	16.1%	13.02	20.75	59.4%	31.4%	36.0%	4.6%	28.3%	28.1%	-0.2%	7.8%	7.6%	-0.2%	30.9%	18.7%	-12.2%
Redwood City	67,724	77,737	14.8%	8.60	21.71	152.4%	46.2%	57.8%	11.6%	28.4%	22.7%	-5.6%	9.9%	6.7%	-3.2%	14.8%	8.5%	-6.3%
Palo Alto	12,220	9,657	-21.0%	1.90	8.82	364.4%	36.2%	49.0%	12.8%	22.1%	23.6%	1.6%	5.2%	3.5%	-1.7%	35.1%	17.7%	-17.4%
Fremont	8,600	10,915	26.9%	7.84	11.59	47.9%	25.8%	30.3%	4.5%	47.5%	39.7%	-7.8%	12.2%	10.6%	-1.6%	14.3%	11.9%	-2.4%
Pleasanton	1,880	17,894	841.2%	11.07	10.70	-3.4%	29.1%	35.1%	6.0%	36.1%	41.4%	5.3%	11.5%	6.6%	-4.9%	21.9%	10.4%	-11.5%
San Ramon	1,544	15,876	928.2%	10.35	13.13	26.9%	30.1%	54.5%	24.4%	36.7%	27.9%	-8.8%	15.2%	5.3%	-9.8%	17.3%	8.2%	-9.1%
Walnut Creek	22,875	35,752	56.3%	1.82	6.74	269.4%	29.0%	41.3%	12.3%	43.2%	38.1%	-5.2%	13.1%	7.9%	-5.2%	14.0%	7.7%	-6.3%
Concord	19,709	28,492	44.6%	13.28	10.62	-20.0%	22.5%	37.1%	14.6%	43.2%	39.8%	-3.4%	12.6%	6.6%	-6.0%	20.7%	9.8%	-10.9%
South San Jose	14,269	14,787	3.6%	9.10	13.46	48.0%	46.3%	51.4%	5.1%	19.7%	18.4%	-1.3%	4.3%	5.1%	0.8%	29.3%	20.3%	-9.0%
San Rafael	18,235	20,670	13.4%	7.62	12.26	60.9%	26.5%	30.5%	4.0%	34.4%	31.7%	-2.7%	10.1%	8.4%	-1.7%	26.7%	17.0%	-9.7%
Vallejo	9,478	16,384	72.9%	10.90	16.74	53.7%	22.4%	26.5%	4.1%	38.4%	28.8%	-9.6%	15.5%	11.7%	-3.8%	21.7%	14.5%	-7.2%
Cupertino	9,965	12,231	22.7%	8.31	15.04	81.0%	36.7%	48.8%	12.1%	34.5%	27.2%	-7.4%	11.3%	8.2%	-3.0%	16.8%	9.3%	-7.6%
Weighted Average[1]	252,632	265,288	23.6%	20.79	33.32	24.4%	35.7%	41.3%	5.6%	17.0%	13.8%	-3.2%	10.3%	5.4%	-3.9%	5.3%	4.9%	0.6%
Standard Deviation	92,278	104,403	13.1%	16.56	23.60	27.0%	19.4%	19.7%	0.3%	11.9%	11.7%	-0.2%	16.0%	15.6%	-2.6%	3.9%	4.4%	0.5%

Source U.S. Bureau of Census, 1980 Urban Transportation Planning Package and 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Areas

[1] weighted by employment size

of how ECs were defined over the two time points.[5] Overall, these 22 ECs represented 47.5 percent of total employment in the 9-county Bay Area in 1980; by 1990, this share rose to 48.2 percent, an indication that the region's employment became slightly more spatially concentrated during the 1980s.

Table 1 also reveals a strong shift toward employment in managerial, executive, and professional occupations across all ECs. This was particularly so in the suburban ECs, especially San Ramon which saw the number of management, executive, and professional jobs increase from 465 in 1980 to 8,656 in 1990, or from 30 percent to 54.5 percent of all jobs. The region's core centers of San Francisco, Oakland, and Berkeley saw a slower rate of growth in these high-end positions.

When examined by class of EC, Table 2 shows that both employment size and density increased, on average, more rapidly in the newer and more peripheral ECs -- the South Bay and suburban centers -- than the older, core centers. In 1980, outlying centers represented 30.0 percent of total employment among the 22 ECs and 14.2 percent of the entire Bay Area labor force; by 1990, these shares had risen to 31.8 and 15.4 percents, respectively. Still, the East Bay core ECs (Oakland, Berkeley, Emeryville) were more than twice as dense as more preferential ones in 1990, and downtown San Francisco was over four times as dense.

Figures 3 and 4 compare 1980 and 1990 changes in employment sizes and densities among the 22 ECs as a function of (centroid-to-centroid Euclidean) distance from the region's primary EC, downtown San Francisco. With some notable exceptions, EC densities and sizes generally fell toward the periphery. Two of the most peripheral ECs, the Silicon Valley (34.02 miles away from downtown San Francisco) and downtown San Jose (38.57 miles away), witnessed the largest absolute gains in employment during the 1980s. In general, employment density increased more rapidly than employment size during the 1980s.[6] In the core of the region (within 8 miles of downtown San Francisco), the EC density gradient steepened whereas in outlying areas there was a slight flattening of the gradient. Concave quadratic curves of the following forms best fit the data (reflecting a rise in EC densities at the peripherally located Silicon Valley/downtown San Jose ECs).

Table 2. Comparison of Employment Size and Density Changes Among Four Classes of Employment Centers, 1980 and 1990

	Employment Center Class				ANOVA	
	Downtown San Francisco	East Bay Core	Silicon Valley, San Jose	Suburban Centers	F Statistic	Prob.
Mean Employment[1]						
1980	426,212	62,160	152,461	37,858	63.20	.000
1990	462,731	73,220	221,580	43,852	45.07	.000
% Change[2]	*8.57%*	*16.75%*	*44.88%*	*63.45%*[3]	*11.73*	*.000*
Mean Density: Workers per Gross Acre[1]						
1980	50.22	24.30	9.51	10.79	33.05	.000
1990	65.45	28.87	14.21	13.54	35.56	.000
% Change[2]	*30.32%*	*17.19%*	*49.19%*	*44.43%*[3]	*8.84*	*.000*

[1] Weighted by size of ECs.
[2] Average percent change across all employment centers within class, weighted by the "midpoint" average of 1980 and 1990 employment for each EC.
[3] Average growth rate is inflated by rapid increases in Pleasanton and San Ramon, whose employment sizes increased by 841 percent and 928 percent, respectively, and whose employment densities increased by 270 percent and 364 percent, respectively.

Sources: U.S. Bureau of Census, 1980 Urban Transportation Planning Package, 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Area.

$$1980: \; Y_i = 38.722 - 2.189X_i + .036X^2_i + u_i \qquad r^2 = .666, \text{prob.} = .000 \tag{2}$$

$$1990: \; Y_i = 48.153 - 2.732X_i + .047X^2_i + u_i \qquad r^2 = .623, \text{prob.} = .000 \tag{3}$$

where: Y_i = EC workers per gross acre, X_i = distance to downtown San Francisco, in miles, and u_i = random disturbance term.

4. SHIFTS IN COMMUTING TO EMPLOYMENT CENTERS: 1980-1990

What was the relationship between patterns of EC growth and commuting among EC workers during the 1980s? In this section, trends in commuting distances and durations are first examined. Increased commuting distances reflect, at least in part, costs borne by society at large since air pollution, energy consumption, and equality of access, many agree, are exacerbated as

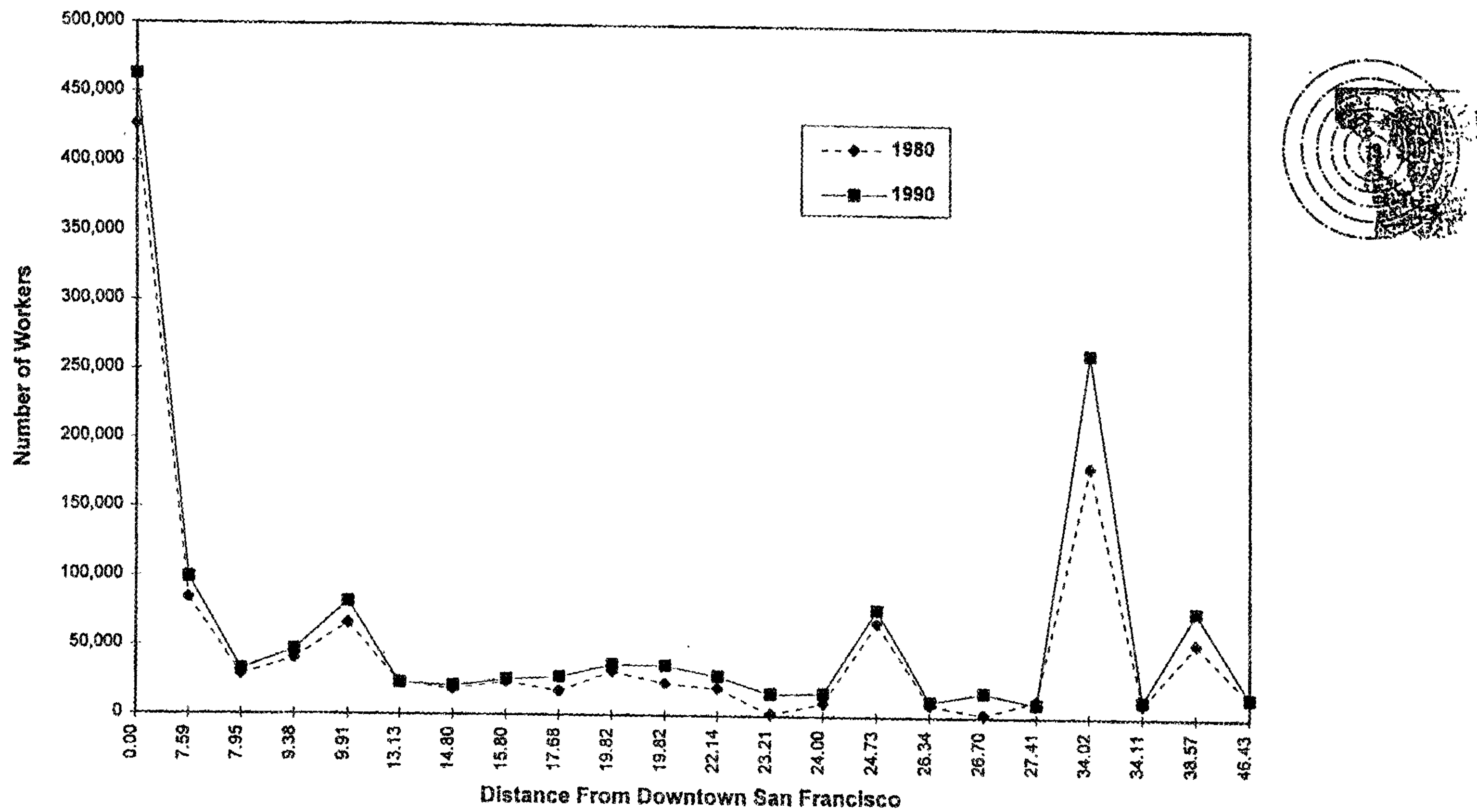


Figure 3. Employment Center Size as a Function of Distance to Downtown San Francisco, 1980 and 1990

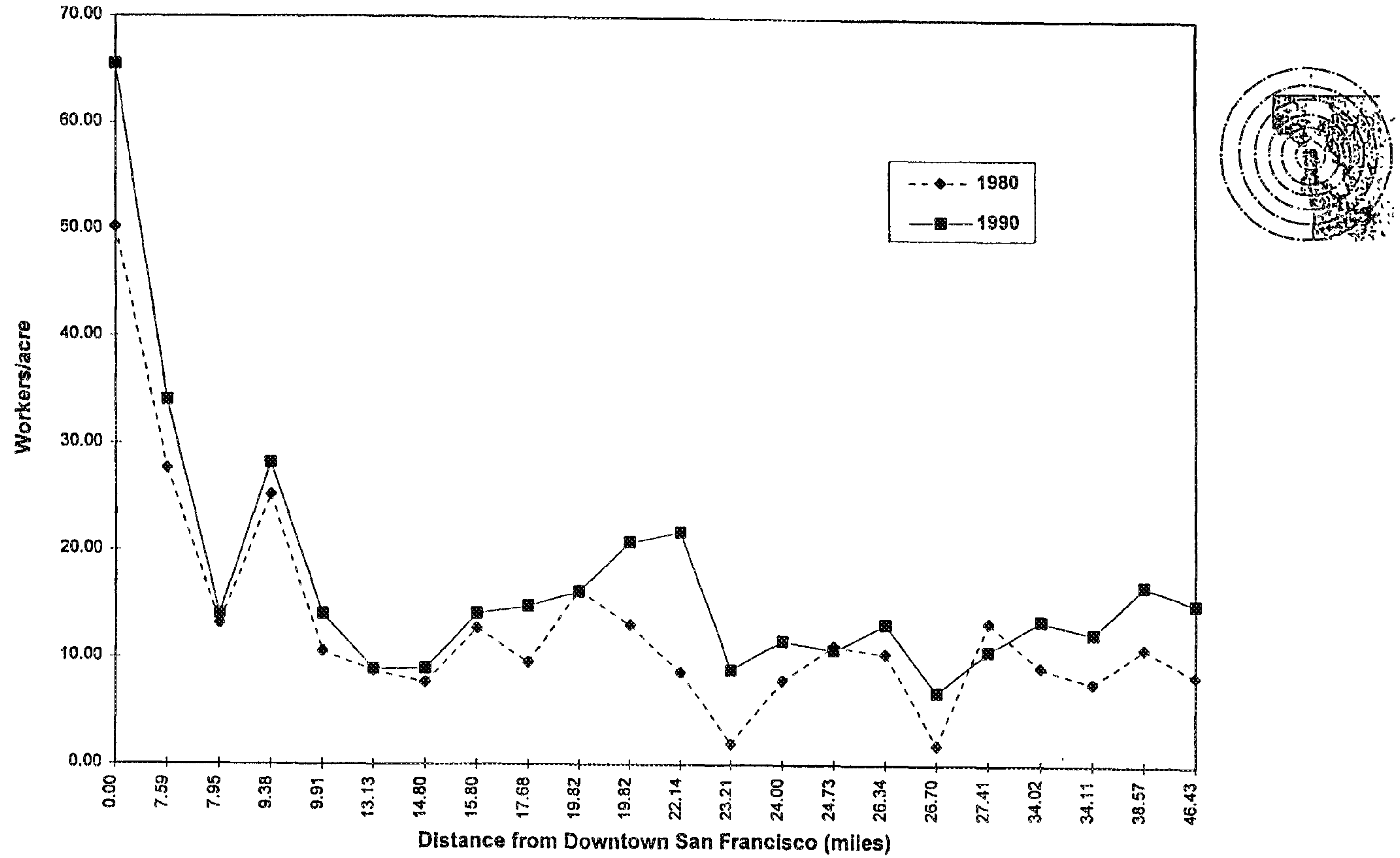


Figure 4. Employment Center Density as a Function of Distance to Downtown San Francisco, 1980 and 1990

trip lengths rise (Rickaby, 1987; Banister, 1992; Hall, 1995). Costs associated with commute times, on the other hand, are largely privately borne. Second, trends in modal splits and average vehicle occupancies are examined across ECs. Like commute distances, these measures are associated with social costs. This is in large part why billions of dollars have gone toward new rail transit systems and High Occupancy Vehicle (HOV) lanes in the U.S. over the past decade. Lastly, data on commuting distances, modal splits, and vehicle occupancies are combined, using equation 1, to estimate trends in VMT per employee -- what we consider to be the most robust measure and strongest correlate of social costs presented in this paper. A partial equilibrium analysis is conducted to infer the degree to which shifts in VMT per employee are attributable to spatial (e.g., commute distance) versus modal (e.g., modal splits and vehicle occupancies) factors. Data are examined and compared among all 22 ECs as well as among the four classes.

Shifts in Commute Distances and Durations

Table 3 shows that for all 22 ECs combined, average one-way "network" commute distances increased 12 percent (from 10.6 to 11.8 miles) and average one-way durations rose by 5 percent, or by 1 minute and 18 seconds (from 27.7 to 29 minutes) during the 1980s. The greatest increases in average distances and durations were for workers at the two fastest growing ECs -- Pleasanton and San Ramon, both on the eastern periphery of the metropolitan area.

When examined among the four classes of ECs, Table 4 reveals several things. Urban centers averaged longer commutes, both spatially and temporally, than more peripheral ones in both 1980 and 1990. However, differences narrowed during the 1980s. Commute distances and durations increased far more rapidly in suburban centers, the Silicon Valley, and central San Jose. Overall, these tables reveal that the trend toward suburban employment growth and subcentering in the Bay Area was associated with a lengthening of commutes, both in terms of average distance and duration. This suggests rising shares of EC commuters incurred higher private costs (in the form of time expenditures) and imposed higher social costs (in the form of more miles traversed) in getting to work during the 1980s.

Shifts in Modal Splits

In a review of 1980-1990 commuting patterns among *suburban residents* of 20 of the largest U.S. metropolitan areas, I concluded that the greatest changes, in relative terms, were

Table 3. Average Commute Distances and Durations Among the 22 Bay Area Employment Centers, 1980 and 1990

Employment Center	Average One-way Commute Distance (miles)			Average One-way Commute Duration (minutes)		
	1980	1990	% change	1980	1990	% change
San Francisco	12.7	13.8	9%	34.0	34.3	1%
Oakland	10.2	11.7	15%	27.5	29.4	7%
Berkeley	7.6	8.3	10%	23.0	23.9	4%
Silicon Valley	8.8	10.2	17%	25.3	28.1	11%
Downtown San Jose	6.9	8.3	21%	21.2	24.6	16%
Emeryville	12.1	11.8	-2%	27.5	28.6	4%
San Leandro	9.2	10.9	18%	24.0	26.4	10%
Hayward	7.9	10.6	34%	21.2	26.3	24%
S.F. Airport	13.8	14.8	7%	26.9	27.8	3%
San Mateo	9.6	10.7	12%	21.6	22.8	5%
San Carlos	9.7	11.9	22%	21.6	24.2	12%
Redwood	8.1	11.0	35%	23.4	24.3	4%
Palo Alto	11.3	11.7	3%	25.8	26.6	3%
Fremont	8.2	8.1	-1%	18.3	20.8	14%
Pleasanton	7.2	12.7	76%	15.7	27.1	73%
San Ramon	9.5	15.3	62%	13.9	31.2	125%
Walnut Creek	9.2	10.6	15%	20.7	25.6	24%
Concord	8.4	10.7	27%	19.8	24.9	26%
South San Jose	8.3	8.1	-2%	20.9	22.5	7%
San Rafael	12.1	14.1	16%	23.7	26.8	13%
Vallejo	6.8	10.1	49%	16.7	20.5	23%
Cupertino	7.6	9.3	21%	20.5	24.6	20%
Weighted Average[1]	10.6	11.8	12%	27.7	29.0	5%
Standard Deviation	2.2	2.0	-8%	5.3	4.1	-22%

Source: U.S. Bureau of Census, 1980 Urban Transportation Planning Package and 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Areas

[1] weighted by employment size

Table 4. Comparison of Average Commute Distances, Durations, and Changes Among Four Classes of Employment Centers, 1980 and 1990

	Employment Center Class				ANOVA	
	Downtown San Francisco	East Bay Core	Silicon Valley, San Jose	Suburban Centers	F Statistic	Prob.
Mean Commute Distance (miles)[1]						
1980	12.70	9.98	7.62	8.42	8.80	.000
1990	13.80	11.00	9.25	11.28	5.28	.009
% Change[2]	*8.62%*	*11.08%*	*19.20%*	*26.66%*	*7.63*	*.001*
Mean Commute Duration (minutes)[1]						
1980	34.00	26.55	22.75	20.10	6.24	.005
1990	34.30	27.30	26.35	25.15	3.83	.034
% Change[2]	*0.83%*	*5.78%*	*14.18%*	*24.17%*	*8.34*	*.001*

[1] Weighted by employment size; one-way measures.
[2] Average percent change across all employment centers within class, weighted by the "midpoint" average of 1980 and 1990 employment for each EC.

Sources: U.S. Bureau of Census, 1980 Urban Transportation Planning Package, 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Area.

modal, marked by reduced transit and ridesharing market shares, rather than spatial or temporal (Cervero, 1995). Table 5 suggests that for *employees* of ECs in the Bay Area, a similar pattern held. In all cases, the share of commutes by drive-alone automobile rose during the 1980s, and in some cases (e.g., south San Jose) quite sharply. In all but two ECs, Pleasanton and San Ramon, ridesharing declined as a percent of total commutes; in these two cases, mandatory trip reduction ordinances prompted large employers to sponsor vanpools and introduce other incentives to promote ridesharing (see: Cervero, 1986; Cervero and Griesenbeck, 1988; Cervero, 1989a). For 9 of the 22 ECs, transit shares actually increased during the eighties, though this occurred mainly in suburban ECs where the base number of transit commuters was very low in 1980. Overall, transit's share of commutes to ECs fell from 19.3 percent in 1980 to 15.4 percent

Table 5. Commute Modal Splits and Average Vehicle Occupancies Among the 22 Bay Area Employment Centers, 1980 and 1990

Employment Center	Total Commuters			MODAL SPLIT: Drive Alone			Carpool			Use Public Transit			Ride a Bike or Walk			Average No. Employees per Vehicle		
	1980	1990	% Change	1980	1990	% pt. Ch	1980	1990	% pt. Ch	1980	1990	% pt. Ch	1980	1990	% pt. Ch	1980	1990	% change
San Francisco	426,212	462,731	8 6%	31 8%	36.3%	4 5%	16.3%	14 9%	-1.4%	42.2%	37 4%	-4 8%	6.4%	7 0%	0.5%	1.47	1 46	0%
Oakland	84,054	99,042	17 8%	56.5%	64.0%	7.5%	16.7%	13.9%	-2.9%	20.2%	15 2%	-5 0%	3.8%	4.5%	0.6%	1.26	1.19	-5%
Berkeley	40,275	46,856	16 4%	44.9%	47.8%	2.9%	14.2%	11.2%	-3 0%	15 2%	13.4%	-1.8%	21.7%	22 9%	1.1%	1.29	1.21	-6%
Silicon Valley	181,671	263,840	45.2%	74.2%	81.3%	7.2%	20 4%	14.3%	-6.2%	1 8%	2.3%	0.5%	1.7%	0.9%	-0 8%	1.17	1.12	-5%
Downtown San Jose	53,766	77,256	43.7%	73.8%	78.5%	4.6%	15.1%	12.6%	-2.5%	4.0%	3.6%	-0.4%	4.6%	3.4%	-1.2%	1 16	1.11	-4%
Emeryville	28,387	32,380	14.1%	68.4%	72.7%	4.3%	19.5%	13.6%	-5.8%	6.5%	7.5%	0.9%	3.3%	3.8%	0.5%	1.23	1.17	-5%
San Leandro	23,037	22,720	-1.4%	75.1%	79 8%	4.7%	17.2%	12.3%	-4 8%	3.6%	4.4%	0.8%	2.3%	2.2%	-0.1%	1.16	1.11	-4%
Hayward	17,320	27,426	58.3%	76.6%	79.3%	2.7%	14.0%	12.5%	-1.5%	4.4%	3 9%	-0 4%	2.6%	2 7%	0.1%	1.15	1.11	-3%
S.F. Airport	65,817	81,772	24.2%	71.9%	74 9%	3 0%	18.3%	16 3%	-1.9%	6 4%	5 2%	-1.2%	2 0%	1.4%	-0.6%	1.24	1.21	-2%
San Mateo	23,780	25,548	7.4%	75.7%	79.3%	3 6%	14.3%	11.2%	-3 0%	4.6%	4 1%	-0 5%	4.5%	3.7%	-0.8%	1.18	1.14	-3%
San Carlos	31,495	36,555	16.1%	72.7%	79 0%	6.3%	18.3%	12.9%	-5.5%	3 4%	3.8%	0.4%	3.3%	2 9%	-0.4%	1.20	1.14	-5%
Redwood City	67,724	77,737	14.8%	66.8%	73 5%	6.7%	15.4%	10 2%	-5.2%	5.0%	3 5%	-1.5%	10.7%	10.8%	0.1%	1.17	1.12	-5%
Palo Alto	12,220	9,657	-21.0%	72.2%	78 5%	6.3%	17.9%	12.1%	-5.8%	2.4%	1.6%	-0 9%	5.3%	3.3%	-2.0%	1.20	1.13	-6%
Fremont	8,600	10,915	26 9%	76.2%	84.0%	7.8%	16.1%	9.9%	-6.2%	2.7%	2.5%	-0 1%	3.5%	2.3%	-1.2%	1.16	1.08	-7%
Pleasanton	1,880	17,694	841.2%	80 4%	83.1%	2.6%	11 1%	13.0%	1.9%	1.0%	1 4%	0 4%	2.6%	1.1%	-1.6%	1.12	1.14	2%
San Ramon	1,544	15,876	928.2%	76.7%	79 0%	2 3%	12.8%	17.8%	5.0%	1.9%	2 0%	0.1%	2.7%	0 5%	-2.3%	1.18	1.35	14%
Walnut Creek	22,875	35,752	56 3%	78.0%	82 4%	4 4%	15 1%	11.3%	-3.8%	2.2%	3 2%	1 0%	3.2%	1.7%	-1 4%	1.15	1.12	-3%
Concord	19,709	28,492	44 6%	76.6%	80.2%	3.6%	16.2%	13.4%	-2.8%	1.8%	3 8%	2 0%	3.6%	1.4%	-2.3%	1.16	1.17	1%
South San Jose	14 269	14,787	3 6%	73 4%	85 5%	12.1%	16.6%	10.2%	-6.3%	4 4%	1.7%	-2 7%	2.2%	1.2%	-1.0%	1.15	1.07	-7%
San Rafael	18,235	20,670	13.4%	69.7%	74 8%	5.1%	18.0%	15.7%	-2.3%	4 4%	3 2%	-1.2%	4.6%	3.4%	-1.2%	1.20	1.16	-3%
Vallejo	9,478	16,384	72.9%	74 0%	79 4%	5.4%	16.6%	14.1%	-2.5%	1.6%	1.2%	-0.4%	5.1%	3.4%	-1.8%	1.18	1.16	-1%
Cupertino	9,965	12,231	22.7%	77.5%	83.3%	5.7%	14.9%	9 3%	-5.6%	1.9%	2.2%	0.2%	3.8%	3.1%	-0.7%	1.15	1.09	-5%
Weighted Average[1]	52,832	65,288	23.6%	55.7%	61.3%	5.6%	17.0%	13.8%	-3.2%	19.3%	15.4%	-3.9%	5.3%	4.8%	-0.5%	1.30	1.25	-4%
Standard Deviation	92,225	104,403	3.2%	19.4%	19.7%	0.3%	1.9%	1.7%	-0.2%	18.0%	15.5%	-2.5%	3.9%	4.4%	0.5%	0.13	0.15	15%

Source: U.S. Bureau of Census, 1980 Urban Transportation Planning Package and 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Areas

[1] weighted by employment size

When modal splits and shifts are examined across classes of EC (Table 6), several distinctive patterns emerge. Commuting shares by single-occupant vehicle and mass transit, and to a lesser extent, by walking and bicycling, are strongly associated with type of employment centers in both years -- the core urban centers averaged relatively high transit, walking, and bicycling shares and low drive-alone shares. Rates of ridesharing were fairly similar across EC classes. However, the only significant differences in modal splits changes were with respect to mass transit and walking/cycling -- with transit usage falling the most in core centers (partly because they had a much larger base in 1980) and non-motorized transport marginally rising in the core centers. Drive-alone percentages rose and ridesharing percentages fell comparably across all EC classes, suggesting that commuting by these modes is strongly shaped by larger, region-wide factors (e.g., trends in transportation prices and service levels).

Collectively, the statistics in Table 6 suggest that the biggest modal effects of job decentralization, particularly when jobs relocate from core to suburban centers, have been shifts from transit riding to drive-alone commuting. This is for spatial, not temporal, reasons. That is, it is not a matter of suburban job centers having lost transit market shares more rapidly (they haven't) or having attracted larger shares of drive-alone commuters (they haven't); rather modal composition has been most effected by spatial shifts of jobs from core areas well-served by transit to peripheral areas that are not. This is consistent with the finding of Cervero and Landis (1992) that showed the share of commutes by mass transit fell from 58 percent to under 3 percent for several thousand Bay Area workers whose jobs had relocated from downtown San Francisco to Pleasanton, San Ramon, and the Silicon Valley during the 1980s.

Shifts in Vehicle Occupancy Levels

From a regional mobility and environmental standpoint, a serious consequence of modal shifts from transit and ridesharing to drive-alone commuting was a decline in average vehicle occupancy levels, shown the last set of columns in Table 5. Overall, average occupancies fell by 4.1 percent from 1980 to 1990, from 1.299 to 1.228 persons per vehicle; this was a faster drop than region-wide occupancies for work trips, which fell from 1.127 to 1.092, or by 3.1 percent. Consistent with earlier findings, San Ramon and Pleasanton witnessed the largest gains in average occupancy levels among their workforces, a product of local trip reduction mandates that

Table 6. Comparison of Commute Modal Splits and Changes Among Four Classes of Employment Centers, 1980 and 1990

	Employment Center Class				ANOVA	
	Downtown San Francisco	East Bay Core	Silicon Valley, San Jose	Suburban Centers	F Statistic	Prob.
Percent:						
Drive-Alone[1]						
1980	31.81	55.65	74.11	72.70	31.59	.000
1990	36.30	61.32	80.67	78.15	29.67	.000
% Pt. Change[2]	*4.51*	*5.70*	*6.55*	*4.97*	*0.73*	*.541*
Percent:						
Ridesharing[1]						
1980	16.33	16.56	19.19	16.49	0.55	.655
1990	14.90	13.14	13.92	12.88	0.36	.779
% Pt. Change[2]	*-1.43*	*-3.42*	*-5.28*	*-3.50*	*0.27*	*.840*
Percent by:						
Mass Transit[1]						
1980	42.22	16.33	2.30	3.23	73.85	.000
1990	37.42	13.32	2.59	3.54	137.15	.000
% Pt. Change[2]	*-4.80*	*-3.05*	*0.29*	*-0.45*	*4.14*	*.021*
Percent by:						
Walking or Biking[1]						
1980	6.40	8.43	2.36	4.64	1.88	.169
1990	7.00	9.20	1.47	3.62	3.02	.057
% Pt. Change[2]	*0.60*	*0.79*	*-0.89*	*-0.75*	*7.00*	*.003*

[1] Weighted by employment size.
[2] Average percentage point change across all employment centers within class, weighted by the "midpoint" average of 1980 and 1990 employment for each EC.

Sources: U.S. Bureau of Census, 1980 Urban Transportation Planning Package, 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Area.

led to aggressive rideshare promotion.

When examined across the four EC classes, Table 7 shows average vehicle occupancy levels were significantly higher for the Bay Area's core centers in both 1980 and 1990, mainly reflecting their significantly higher shares of transit commutes. However, the relative decline in vehicle occupancy levels was comparable across EC classes.

Table 7. Comparison of Average Vehicle Occupancy Levels and Changes Among Four Classes of Employment Centers, 1980 and 1990

	Employment Center Class				ANOVA	
	Downtown San Francisco	East Bay Core	Silicon Valley, San Jose	Suburban Centers	F Statistic	Prob.
Mean Employees Per Vehicle[1]						
1980	1.470	1.261	1.164	1.160	41.97	.000
1990	1.460	1.191	1.114	1.116	9.31	.000
% Change[2]	*-0.43%*	*-5.35%*	*-4.41%*	*-3.76%*	*0.50*	*.687*

[1] Weighted by employment size.
[2] Average percent change across all employment centers within class, weighted by the "midpoint" average of 1980 and 1990 employment for each EC.

Sources: U.S. Bureau of Census, 1980 Urban Transportation Planning Package, 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Area.

Shifts in Commute VMT Per Employee

Merging data on commute distance, modal, and occupancy data yielded insightful estimates of commute VMT per employee. As noted, this measure encapsulates the richest information and, we believe, is most strongly associated with transportation externalities among all of the measures examined so far. Table 8 shows that among all ECs combined, average (one-way) VMT per employee rose from 7.1 in 1980 to 8.7 in 1990, a 23 percent rise. This is a direct

Table 8. Commute VMT per Employee Among the 22 Bay Area Employment Centers, 1980 and 1990

Employment Center	Commute VMT per Employee			SENSITIVITY TEST: Commute VMT per Employee: Holding Distance Constant*			SENSITIVITY TEST: Commute VMT per Employee: Holding Average Occupancies and Modal Splits Constant*		
	1980	1990	% change	1980	1990	% change	1980	1990	% change
San Francisco	6.3	7.4	17%	6.3	6.4	1%	6.3	6.9	10%
Oakland	7.3	9.2	25%	7.3	7.9	7%	7.3	8.6	17%
Berkeley	5.3	6.3	19%	5.3	5.6	6%	5.3	5.8	10%
Silicon Valley	7.4	9.2	24%	7.4	7.8	5%	7.4	8.7	16%
Downtown San Jose	5.9	7.4	25%	5.9	6.1	3%	5.9	7.1	19%
Emeryville	9.9	10.1	3%	9.9	10.1	2%	9.9	9.7	-2%
San Leandro	7.9	9.6	22%	7.9	8.0	2%	7.9	9.1	16%
Hayward	6.8	9.4	40%	6.8	7.0	3%	6.8	9.0	34%
S.F. Airport	10.4	11.9	15%	10.4	10.9	5%	10.4	11.4	10%
San Mateo	8.0	9.5	19%	8.0	8.3	5%	8.0	9.1	14%
San Carlos	7.8	10.3	32%	7.8	8.2	5%	7.8	9.6	22%
Redwood	6.8	9.5	39%	6.8	6.9	1%	6.8	8.9	29%
Palo Alto	9.5	10.6	11%	9.5	10.2	8%	9.5	9.9	4%
Fremont	6.9	7.4	7%	6.9	7.4	7%	6.9	6.9	-1%
Pleasanton	6.5	11.3	75%	6.5	6.4	-2%	6.5	11.4	76%
San Ramon	8.7	12.5	44%	8.7	7.5	-13%	8.7	13.4	55%
Walnut Creek	7.9	9.3	19%	7.9	7.9	0%	7.9	8.8	12%
Concord	7.0	9.0	28%	7.0	6.9	-2%	7.0	8.8	25%
South San Jose	7.0	7.5	7%	7.0	7.6	9%	7.0	6.9	-1%
San Rafael	9.6	12.2	27%	9.6	10.3	7%	9.6	11.6	21%
Vallejo	5.7	9.1	60%	5.7	6.0	6%	5.7	8.8	55%
Cupertino	6.6	8.6	30%	6.6	7.0	6%	6.6	8.1	23%
Weighted Average**	7.1	8.7	23%	7.1	7.4	4%	7.1	8.3	16%
Standard Deviation	1.2	1.5	21%	1.2	1.3	7%	1.2	1.5	23%

Source: U.S. Bureau of Census, 1980 Urban Transportation Planning Package and 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Areas

* held constant at 1980 levels

** weighted by employment size

product of average commute distances and drive-alone shares having increased and average vehicle occupancy levels and transit/ridesharing shares having fallen during the 1980s. (A fairly minuscule contribution was the decline in walking and cycling modal shares in outlying centers, the very areas with the fastest employment growth.) We also see that average commute VMT rose in *all* 22 ECs. The largest increases occurred at the suburban centers of Pleasanton, Vallejo, and San Ramon.

Since "VMT per employee" embodies the spatial, modal, and occupancy dimensions of commuting, patterns revealed by Table 8 should reinforce earlier findings. The strongest contribution to increased VMT per employee is thought to be increased commute distances. As shown earlier in Table 2, average commute distances varied sharply between urban core and peripheral ECs. Additionally, outlying centers experienced the fastest growth in average commute distances during the 1980s. Transit versus drive-alone modal splits as well as average occupancy levels also varied significantly among classes of ECs, though 1980-1990 shifts were more weakly associated. Thus, while lengthening commutes cut across all ECs and therefore effected the Bay Area's workforce broadly, the majority of employees in all ECs (except downtown San Francisco) commuted alone in both 1980 and 1990, meaning modal shifts away from higher occupancy modes effected a smaller share of the workforce.

These inferences are supported by the sensitivity tests shown in the last set of columns in Table 8. The tests attempt to ferret out the relative contribution of rising distances versus falling occupancy levels and shares of transit and ridesharing commuting toward the recorded gains in VMT per employee. In the first test, VMT per employee is estimated by holding commute distances constant. Here, the average commute distance to each EC in 1990 is assumed to equal that of 1980; modal split and occupancy data are left unchanged. The second test reverses the scenario -- here, modal splits and occupancy levels are held constant, and actual 1980 and 1990 distance data are used. Through these partial equilibrium tests, the relative contribution of the spatial versus modal/occupancy dimensions of rising VMT per employee can be inferred.

Comparing the sensitivity test results, it is apparent that rising distances have contributed the most to VMT per worker. If only occupancy/modal splits are allowed to change, the estimated average VMT per employee, among all ECs, increases by 3.1 percent during the

1980s. If, on the other hand, only distances are allowed to change, then the increase is 15.2 percent.[7] These results suggest that rising trip lengths contributed roughly five times as much to higher commute VMT per employee than falling occupancy levels and transit/ridesharing modal splits. That is, over 80 percent of the growth in per capita VMT, we estimate, was attributable to longer distance commutes.[8] Comparing the "% change" columns of the two tests shows that increased commute distances had the strongest effect on VMT per employee gains in 18 of the 22 ECs.[9] Rising average commute distances had proportionately the greatest effect on rising average VMT in the two fastest-growing ECs, Pleasanton and San Ramon.

Lastly, comparisons of VMT per employee as well as the sensitivity test results across EC classes and over time further illuminate these relationships. Table 9 shows that outlying ECs averaged higher VMT per worker than the core ECs, and that the differential widened during the 1980s. The fastest growth in per capita VMT occurred among the workforces of suburban centers; in contrast, VMT rates increased more slowly among the workforces of downtown San Francisco and the East Bay core. From the sensitivity tests, we see that spatial, modal, and occupancy factors contributed differently to VMT growth among the four EC classes. Rising average commute distances contributed most to higher VMT rates in all four EC classes. However, the distance factor had proportionately the greatest effect on rising VMT rates in the peripheral work centers. Falling vehicle occupancies and non-drive-alone shares exerted a stronger effect on rising VMT rates in the East Bay core than in outlying employment centers.

5. CONCLUSION AND POLICY INFERENCES

During the 1980s, employment growth in the San Francisco Bay Area was characterized by continued decentralization, mainly in the form of subcentering and highlighted by the emergence of major suburban employment agglomerations in the Silicon Valley, Pleasanton, San Ramon, and the San Francisco International Airport area. While a significant transportation impact of subcentering has been modal in nature (i.e., shifts from higher to lower occupancy vehicles), in terms of absolute contribution to rising per capita VMT, the strongest influence has been a lengthening of average commutes. In both 1980 and 1990, the drive-alone automobile was the dominant mode for getting to work, meaning the commuting habits of most workers

Table 9. Comparison of Commute Modal Splits and Changes Among Four Classes of Employment Centers, 1980 and 1990

	Employment Center Class				ANOVA	
	Downtown San Francisco	East Bay Core	Silicon Valley, San Jose	Suburban Centers	F Statistic	Prob.
Mean VMT per Employee[1] BASE CASE:						
1980	6.30	7.26	7.09	8.04	0.56	.649
1990	7.40	8.59	8.81	10.13	1.64	.211
% Change[2]	*17.14%*	*19.49%*	*24.14%*	*27.74%*	*1.21*	*.433*
Mean VMT per Employee[1] CONSTANT DISTANCE:[3]						
1980	6.30	7.26	7.09	8.04	0.56	.649
1990	6.37	7.68	7.41	8.17	0.52	.673
% Change[2]	*1.50%*	*6.06%*	*4.22%*	*2.95%*	*0.54*	*.664*
Mean VMT per Employee[1] CONSTANT OCCUPANCY & MODAL SPLIT:[4]						
1980	6.30	7.26	7.09	8.04	0.56	.649
1990	6.90	8.06	8.34	9.68	1.47	.255
% Change[2]	*9.70%*	*11.66%*	*16.98%*	*21.57%*	*0.693*	*.568*

[1] Weighted by employment size.
[2] Average percentage change across all employment centers within class, weighted by the "midpoint" average of 1980 and 1990 employment for each EC.
[3] Average commute distance held constant at 1980 level for each employment center.
[4] Average vehicle occupancy levels and modal splits held constant at 1980 level for each employment center.

Sources: U.S. Bureau of Census, 1980 Urban Transportation Planning Package, 1990 Census Transportation Planning Package, San Francisco-Oakland-San Jose Consolidated Metropolitan Statistical Area.

commuted by transit to urban centers in 1980 had switched to car commuting by 1990 as a consequence of job relocation to the suburbs (Cervero and Landis, 1992), these commuters made up a relatively small share of the region's commuting market. However, the trend toward job decentralization and subcentering influenced the distance of commute for far larger shares of Bay Area workers, resulting, on average, in longer journeys. While other studies suggest job decentralization shorten commutes, this has been mainly in terms of recorded travel times, and typically measured at the aggregate, metropolitan-wide level (e.g., Gordon et al., 1991). Our study has sought to refine the analysis of the spatial implications on commuting by disaggregating data among employment centers, measuring highway and transit network distances, and examining commuting behavior during the entire 1980-1990 window of rapid suburban employment growth. When combining refined commute distance measures with data on shifts in modal distributions and occupancy levels, it is clear that employment decentralization has been associated with substantial increases in commute VMT per employee, at least in the San Francisco Bay Area. Since shifts in VMT per employee are thought to be strongly associated with transportation externalities, the broader social implications of job decentralization on commuting, we would argue, deserve more public policy attention.

What might explain the trend toward lengthening commutes in spite of job decentralization? The expectation has long been that the migration of jobs to the suburbs, where most of the metropolitan labor force resides, would shorten commuting. However, this research shows that the relationships between subcentering and commuting are complex, and using aggregate, region-wide data to infer relationships is fraught with difficulties and can be misleading. In other research (Cervero, 1996; Cervero and Wu, 1997), we have found that jobs-housing imbalances have worsened in and around many large suburban employment centers in the Bay Area due to lags in housing production. We have suggested that exclusionary and fiscal zoning practices have been largely to blame for laggard housing production, and as a consequence have formed frictions to residential mobility. Recent research also presents compelling evidence for maintaining viable urban centers to preserve the ridership base of mass transportation and ridesharing modes (Holtzclaw, 1994; Frank and Pivo, 1994); while workers at CBDs and urban job centers average relatively long commutes, they also tend to commute in higher occupancy modes, resulting in relatively low levels of VMT per employee. The results of our research are consistent with propositions that balanced growth, the removal of barriers to residential mobility, and more transit-oriented development could enhance mobility to employment centers while also promoting broader environmental and social objectives.

Notes

1. The major data sources used in this study were the 1990 Census Transportation Planning Package Urban Element (CTPP-UE), released in 1993, and the 1980 Urban Transportation Planning Package Urban Element (UTPP-UE), released in 1985. Tapes for these two Bay Area census data bases were provided by the Metropolitan Transportation Commission (MTC). The 1990 CTPP-UE consists of three parts. Part I contains data by place-of-residence, Part II tabulates data by place-of-employment, and Part III provides work-trip interchange data. Characteristics of employed-residents and employees were derived from Parts I and II respectively, while work-trip interchange (by mode, travel time, origin-destination pairs) and vehicle occupancy data were acquired from Part III. Comparable data were obtained from the 1980 UTPP-UE. The two census years used different census geographies, however. The 1990 Bay Area CTPP-UE disaggregates data to the Traffic Analysis Zone, or TAZ, level (1,099 in all), while the 1980 Bay Area UTPP-UE breaks down data at the census tract level (1,382 in all). To make the data bases comparable, the 1990 CTPP-UE data were converted to the census tract levels using equivalency tables provided by MTC.

2. The journey-to-work responses are tabulated from the "long form" census, distributed to around one-in-eight urban American households. Specific questions posed in both 1980 and 1990 that generated the data used in this study were: duration -- "how many minutes did it usually take this person to get from home to work last week?"; occupancies (for personal vehicle commutes) -- "how many people, including this person, usually rode to work in the car, truck, or van last week?"; and mode choice -- "how did this person usually get to work last week?".

3. The 1980 and 1990 census data break down commute trips by automobile, van, truck, and motorcycle according to vehicle occupancy classifications that allow average occupancy levels to be fairly accurately determined. Walk and bicycle trips are treated as zero vehicle occupancy trips (e.g., they do not contribute to VMT). Drive-alone (which constituted 68.8 percent of regional commutes in 1990) are by definition single-occupant trips, as are assumed to be motorcycle commutes. Vehicle pools by car and van are recorded by specific occupancies, from 2 up to 10 occupants, in both censuses (see: JHK and Associates, 1995). Carpools and vanpools with over 10 occupants are assumed to average 12 occupants based on statistics provided by RIDES for Bay Area Commuters, Inc. (Since California Public Utility regulations define vehicles with over 15 occupants as for-hire, common-carrier modes, with expensive minimum insurance and indemnity requirements, vanpools rarely, if ever, exceed 15 occupants.) Estimating average occupancies for bus transit and rail transit trips required more assumptions to be invoked. Based on occupancy statistics available from the 1990-1991 Bay Area Transportations Survey (obtained from the Metropolitan Transportation Commission), work-trip (normally peak-hour) occupancies were assumed to be: 35 for public and private bus transit as well as cable car (San Francisco Municipal Railway); 70 for light rail transit (San Francisco Municipal Railway and Santa Clara County Light Rail Transit); and 220 for heavy rail (Bay Area Rapid Transit) and commuter rail (CalTrains)

services. For all transit modes, the number of vehicle trips were rounded up to the next whole numbers based on divisibles from assumed occupancy levels. For instance, if an O-D pair yielded 50 bus transit trips, this was treated as 2 vehicle trips (since 50/35 = 1.42, rounded up to 2). Lastly, commutes by ferryboat (less than 0.1 of the 1990 regional total) were ignored in the analysis, as were "work at home" (3.5 of the 1990 total) since these employees were, by definition, did not work at ECs.

4. The two exceptions were San Francisco Airport Area and Redwood City, each of which had over 80,000 employees in 1990.

5. Employment within the city limits of Palo Alto grew by 28 percent from 1980 to 1990. However, given the rigid criteria used for defining ECs, the contiguous tracts that made up the Palo Alto EC in 1990 had fewer workers than those making up the Palo Alto EC in 1980. This is because Palo Alto's employment had spread out into relatively low density office complexes during the 1980s -- i.e., job growth occurred in tracts that did not meet the minimum density thresholds set for defining 1990 ECs. Thus, while the city of Palo Alto saw job growth in the 1980s, the subset of EC tracts actually registered an employment loss.

6. The 1980-1990 paired sample t-statistics (and probabilities) for difference of means were:
EC density -- 4.81 (.000); EC size -- 3.76 (.004).

7. The increase in VMT per employee for each sensitivity test is less than the estimated increase (i.e., "base case") since inputs are based on 1980 data which were more favorable to lower per capita VMT (e.g., shorter commute distances, higher non-drive alone modal shares, and higher average vehicle occupancies).

8. This estimate is based on simple factoring. Of the 22.96 percent total increase in commute VMT per employee from 1980 to 1990, the partial equilibrium analysis suggested 15.23 percentage points of the increase were attributable to longer distance commutes, 3.13 percentage points were attributable to modal split shifts and lower average occupancies, and presumably the residual (4.60 percentage points) represented a combination of interactive influences (e.g., longer commutes to suburban centers could have a greater depressing effect on transit market shares) and errors (from reporting, measuring, and rounding off). Ignoring the unaccounted for residual (i.e., assuming its influences were proportionately spread among the "accounted for" factors) results in an estimated contribution from longer average commute distances of 83 percent [15.23/(15.23 + 3.13)] and an estimated contribution from changing modal splits and vehicle occupancies of 17 percent [3.13/(15/23 + 3/13)].

9. This is revealed by the higher "% change" figures in the second than the first sensitivity test. Only in the cases of Emeryville, Palo Alto, Fremont, and south San Jose were declining transit/ridesharing modal splits and vehicle occupancy levels a stronger contributor to rising VMT per employee.

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