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Efficient Urbanisation: Economic Performance and the Shape of the Metropolis

Robert Cervero

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Summary. The influences of urban form and transport infrastructure on economic performance show up in several contemporary policy debates, notably 'sprawl versus compact city' and in the developing world, the future of mega-cities. This paper probes these relationships using two scales of analysis. At the macro scale, an econometric analysis using data across 47 US metropolitan areas reveals that employment densities and urban primacy are positively associated with worker productivity, suggesting the presence of agglomeration economies. Congested freeways are shown to be a consequence of strong economic performance. An intrametropolitan analysis using data on sub-districts of the San Francisco Bay Area generally reinforces the findings of the macro-scale analysis. In the Bay Area, labour productivity appears to increase with size of labour-marketshed and high accessibility between residences and firms. Higher employment density and well-functioning infrastructure also contribute positively to economic performance.

1. Introduction

Empirically, the relationship between urban form and economic performance is fairly murky. Still, the physical make-up and shape of a city are widely thought to carry with them significant economic costs and benefits. Spread-out, auto-oriented cities, for instance, are commonly associated with high levels of infrastructure service demands and resource consumption. One recent study suggests that places with sprawling, auto-centric landscapes are poor economic performers. Using data from 46 international cities, Kenworthy and Laube (1999, p. 632) found gross regional product per capita was generally higher in less auto-dependent cities:

> Car use does not necessarily increase with increasing wealth, but tends to fall in the most wealthy cities.

In the developing world, the debate over urban form and economic performance has less to do with the shape of cities and more to do with their size. Giant cities are often considered dysfunctional—too congested, unserviceable, fiscal drains on national treasuries and unmanageable from a governance standpoint. To the degree that large cities suffer from agglomeration diseconomies and other deficiencies, it is unclear whether this is a product of inherent or structural

Robert Cervero is in the Department of City and Regional Planning at the University of California at Berkeley, Hearst Field Annex, Building B #1850, Berkeley, California, 94720-1850, USA. Fax: 510 643 9576. E-Mail: robertc@uclink.berkeley.edu. *This research was supported by a grant from the Lincoln Institute of Land Policy. Two graduate students from the University of California at Berkeley, Tom Maguire and Mike Duncan, assisted the author in compiling data used in this analysis.*

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inefficiencies associated with 'bigness' or whether it is an outcome of poorly planned and managed growth.

This paper probes these questions by empirically examining the relationships between labour productivity and several indicators of urban form as well as quality of transport infrastructure and services. It is postulated that, all else being equal, large cities that are compact and that enjoy good accessibility matched by efficient transport infrastructure (i.e. good mobility) are among the most productive of all urban settlements. Experiences suggest that such outcomes—compactness and land-use/transport integration—are not products of happenstance, but rather of decades upon decades of carefully managed and guided urbanisation. Economically vibrant and ecologically sustainable cities like Curitiba in southern Brazil, Stockholm and Singapore are cases in point (Cervero, 1998).

2. Theory: Urban Form and Economic Performance

Urban economics provides a theoretical foundation for conceptualising how urban form influences economic outcomes (Marshall, 1952; Mills and Hamilton, 1989; Bogart, 1998). An inherent benefit of efficiently managed growth is high labour productivity. This, theory holds, is attributable to two key factors: efficient regions provide firms with good access to a comparatively large pool of workers, within any given distance, and correspondingly aid job searches among members of a labour force; and, efficient transport infrastructure increases the speed, and thus reduces the time, of linking labour markets and business enterprises.

Benefits are also thought to accrue from size, or what economists call 'urbanisation economies of scale'. An enlarged labour market, all else being equal, increases firm access to specialised skills, intermediaries and sub-contractors, and factor inputs. Large cities, theory holds, support a fuller articulation of the labour market, permitting higher degrees of specialisation and horizontal linkages among firms (Krugman, 1993). In a similar vein, bigness works in favour of a more complete clearing of the labour market, more nearly matching each worker with his or her ideal job and simultaneously filling each position with someone nearly profiling its ideal labourer (Simpson, 1992; Acemoglu, 1996). Large cities, theorists contend, also function as incubators for the spread of knowledge and innovations across industries and firms. These benefits gain importance as regional economies become increasingly diversified, horizontally integrated and post-Fordist in their organisation and modes of production. Similarly, efficiency derives from the co-location of housing and employment growth—i.e. the jobs–housing balance—which can lower commuting costs and in turn increase labour productivity (for example, workers spend more time at the workplace as opposed to getting there) (Cervero, 1996; Kain, 1993). Efficient transport—and, in particular, good integration of regional infrastructure and urban settlements—enhance mobility, which can help to offset the effects of poor accessibility.

3. Empirical Investigations

Comparatively little empirical research has been carried out to date to test these propositions. Past research has focused mainly on the effects of city size on productivity. Most studies have estimated production functions for specific industries, aggregated across metropolitan areas, reaching the general conclusion that productivity rises with city size, of the order of 5–15 per cent as population doubles (Shefer, 1973; Sveikauskas, 1975; Segal, 1976; Soroka, 1984; Beeson, 1987). Glaeser *et al.* (1992) present evidence that dynamic advantages—in terms of ability to adapt to changing technologies and market trends—accrue to cities that are large, regardless of the extent of specialisation in the city.

The links between economic performance and not just city size but also factors like labour-force proximity and transport performance have only recently received empirical attention. While the impacts of transport infrastructure investments on economic outputs have been empirically investigated, with generally moderate rates of return recorded (see Boarnet, 1997a, for a review), few studies have examined the simultaneous effects of city size, urban form and mobility levels on economic outcomes. Most notable in this regard is the work of Rémy Prud'homme and his colleagues from the University of Paris. Prud'homme's research group has amassed an impressive array of cross-sectional data to probe how city size, labour force proximity and commuting speeds are associated with regional economic performance across several countries. Their work reveals strong relationships and suggests that spatial planning and good transport infrastructure meaningfully increase the economic output of a city. Using data from French and Korean cities, Prud'homme and Lee (1999) found the elasticity between factors like commuting speeds and labour productivity to be around + 0.30. While their work uses metrics of labour-marketsheds to get at proximity of workers to firms, it fails to incorporate measures of accessibility across a metropolitan region, something that the research reported in this paper explicitly undertakes.

The studies reviewed above examine how the physical make-up of cities influences economic performance. Another line of enquiry germane to this question is the relationship between growth management tools and economic growth. Critics charge that urban containment policies, like urban growth boundaries, eventually place regions at a competitive disadvantage by driving up land costs and eventually wages. Porter (1997) contends that the land-rent increases in land-constrained cities like Portland, Oregon, have as much to do with the desirability to live, work and do business in a well-planned, well-managed city as they do with limits on land supplies. A recent study by Nelson and Peterman (2000) found empirical evidence of this using data from 182 US metropolitan areas, 26 of which have had growth management programmes in place since 1982. The authors statistically showed that policies like urban growth boundaries and building caps are positively associated with economic performance.

Taken together, the preponderance of empirical evidence to date points toward a positive relationship between productivity and compact, accessible and highly mobile regions. As noted, however, the impacts of such parameters on economic performance have largely been studied individually. The analysis that follows aims to study the factors collaterally, building upon the seminal work of Prud'homme and his colleagues.

4. Policy Context

Empirical analyses of urban structure and economic performance can inform several important contemporary policy debates. One involves the relative merits and demerits of 'sprawl' versus 'compact city'. To date, the debate has focused centrally on the question of which settlement pattern is inherently the least costly, defined mainly in terms of public-sector outlays and natural resource consumption. The seminal work on this, *The Cost of Sprawl*, studied hypothetical costs for serving six simulated communities of varying housing densities (Real Estate Research Corporation, 1974). The study concluded that

> sprawl is the most expensive form of residential development in terms of economic costs, environmental costs, natural resource consumption, and many types of personal costs (Real Estate Research Corporation, 1974, pp. 2–7).

Subsequent updates have reached similar conclusions, spawning various policy initiatives that promote regional growth management (Duncan and Frank, 1989; Burchell *et al.*, 1998) and preserve agricultural lands and open spaces (American Farmland Trust, 1994). The state of New Jersey, for instance, endorsed the 'compact city' option in its statewide growth management plan based on research showing that in order to accommodate half a million new residents over the next 20 years, the state would save $1.3 billion in infrastructure construction and $400 million in annual operating and maintenance costs relative to a future of spread-out development (Burchell, 1992). Sprawl was also estimated to impose far higher environmental costs than more contained, mixed-use patterns of urbanisation. More recently, Burchell (2000) estimated that if one-third of America's future growth was directed towards central cities and inner suburbs and developed with modest changes (slightly higher densities, more mixed uses, traffic calming), the US would save approximately $250 billion in infrastructure and public service outlays over the next 25 years—about $2500 per household. In contrast to these findings, a recent study of 55 jurisdictions in the San Francisco Bay Area found no significant differences in municipal revenue generation and debt loads with respect to various measures of land-use mix, density and urban form (Landis, 2001). The implication of this study is that the fiscal impacts of different patterns of urbanisation are inconsequential—a finding that will no doubt stir the pot of controversy swirling around the pros and cons of sprawl versus compact city.

Largely absent from the debate over 'preferred' settlement patterns has been much discussion or analysis of benefits. That is, a focus on fiscal costs, rather than economic benefits, has driven much of the scholarly research so far on optimal patterns of urbanisation and transport investment policy. In the US, the argument that sprawl should be held in check on fiscal grounds has resonated across political lines, with republican (New Jersey), democratic (California) and independent (Minnesota) governors alike having introduced anti-sprawl initiatives in recent years, most under the banner of 'smart growth'. Evidence on the economic productivity implications of different patterns of urbanisation can help to inform and shape these fairly controversial policies.

In the developing world, policy-makers have formed overall negative opinions about huge metropolises. Mega-cities like Jakarta, Cairo and São Paulo are often criticised for being too expansive and too expensive to manage and govern efficiently. The world's giant cities, critics contend, suffer woefully from the ill effects of agglomeration. Overcrowding is manifested in the form of traffic paralysis, squatter settlements, street crimes and foul air. Underpinning this argument are theories on 'optimal city size' advanced by Alonso (1971), Richardson (1973), Henderson (1974) and Segal (1976) among others. Beyond a certain point, likely to be in the range of 5–10 million inhabitants, the marginal social costs of additional residents and industries are thought to exceed the marginal social benefit. Hyperurbanisation is also blamed for the stagnation of agrarian-based economies by draining rural areas of human capital. The great Mahatma Ghandi and Mao-Tse-Tung shared a distrust of large cities and often preached the virtues of rural-based development (Prud'homme, 1996). This 'big is bad' world view has over the years prompted various policy reactions, ranging from population stabilisation programmes aimed at lowering birth rates to growth-pole programmes that target economic growth at second- and third-tier settlements (Rondinelli, 1985; Soegijoko, 1992).

While concerns over agglomeration diseconomies have been the focus of spatial planning in the developing world, problems like spatial mismatches and jobs–housing imbalances are also acute. The urban labour market in many big cities is highly stratified, marked by an absence of movement between the labour markets for managerial and technical personnel and the market for manual labourers, and between the market for labourers and that for informal-sector jobs (Kojima, 1996). Correspondingly, residential neighbourhoods are also stratified geographically into formal, quasi-formal and informal housing settlements, reinforced by differences in language, religion, ethnicity and customs. Evidence that reveals how new spatial patterns and transport-land-use arrangements might influence the economic future of big cities clearly would be of considerable policy value in the developing world.

5. Research Approach

This paper seeks to add to the evolving empirical literature on urban structure, infrastructure provisions and economic performance. Two separate empirical analyses are carried out—one at the macro level, based on cross-comparisons among 47 US metropolitan areas; and the other at a more micro scale, based on cross-comparisons among 'super-districts' in the San Francisco Bay Area. Each grain of analysis offers certain methodological advantages and disadvantages; by combining the two, and thus triangulating the research design, it is felt that richer insights can be gained that tap into the particular strengths of each study approach.

The general relationship studied at both grains of analysis took the following form:

$$E = f(\mathbf{S}, \mathbf{A}, \mathbf{F}, \mathbf{T}, \mathbf{C})$$

where, E = economic output, expressed as productivity per worker; $\mathbf{S}$ = size vector, related to the overall population and geographic scale of an area; $\mathbf{A}$ = accessibility vector, reflecting the relative proximity of firms to labour markets; $\mathbf{F}$ = urban form vector, representing variables that capture the density and degree of primacy of an area; $\mathbf{T}$ = transport infrastructure variable, representing relative speed and performance of services; and $\mathbf{C}$ = control variables.

Compact, accessible cities have high levels of connectivity between places that represent opportunities for spatial interaction among firms, their labour forces and intermediaries. Accessibility stands as a proxy for efficient urban structure, representing urbanisation patterns like jobs–housing balance and infill development. Consistent with theory, size and agglomeration (for example, density and primacy) also increase productivity through a combination of labour market pooling, savings in transporting inputs and technological and information spillovers. Also in keeping with theory, transport infrastructure raises productivity by increasing average travel speeds. In this model form, the transport variable comes closest to representing the capital input component of a traditional Cobb–Douglas production function. While improved mobility no doubt raises productivity to the degree that factor inputs (for example, labour, raw materials, intermediate goods) can be more swiftly moved to their destinations, empirical evidence on this is muddled; studies revealing that public investment in roads increases economic output (Aschauer, 1989) are contradicted by those (Holtz-Eakin, 1994; Garcia-Mila *et al.*, 1996) concluding that firms would be at least as well off if tax proceeds used to finance infrastructure were never exacted from the private sector in the first place.

6. Macro Analysis

Relationships between urban form and economic performance are best captured at a metropolitan scale of analysis since metropolitan areas most closely correspond with labour-marketsheds—the spatial dimensions from which firms and businesses draw upon labour inputs. While census statistics are readily available at the metropolitan scale, unfortunately other important variables pertinent to this study, like labour force accessibility, are not available in a consistent format across metropolitan areas. Data limitations thus inhibit empirical analyses at the metropolitan scale.

A core database used for the macro-scale phase of this research is a comprehensive database on US cities and suburbs compiled by the Center for Urban Policy Research (CUPR) at Rutgers University (Center for Urban Policy Research, 1999). This database was supplemented by statistics compiled from the 1990 census, the National Personal Transportation Study and other secondary sources. In all, fairly complete data were available for 47 US metropolitan statistical areas.[1] The variables used in the macro analysis, including the sources of each, are shown in Table 1.[2] Some of these variables are imperfect proxies—'employment density' and 'city primacy', for example, are influenced and potentially biased by political boundaries. Nevertheless, collectively these variables are felt to capture core attributes of urban form, transport infrastructure, and employment composition.

Table 1. Names, definitions and sources of variables used in predictive modelling for macro-scale analyses

Variable	Definition	Source
GMP per worker	Gross metropolitan product per worker, 1990, in $	CUPR, *State of the Nation's Cities*, 1999
Freeway density	Vehicle miles travelled per lane-mile freeway capacity per day, 1990	Texas Transportation Institute, *Estimates of Urban Roadway Congestion,* 1993
City primacy	Proportion of metropolitan employment in primary central city, 1990	US Census, 1990, Census Transportation Planning Package, Part 2
Employment density	Number of workers per gross square mile of land area	US Census, 1990, summary tape file 1
MSA population	Population of metropolitan statistical area, 1990	US Census, 1990, summary tape file 1
City population	Population of primary central city, 1990	US Census, 1990, summary tape file 1
Service employment	Gross employment in general business and personal service industries	CUPR, *State of the Nation's Cities*, 1999; US Department of Commerce, Bureau of Labor Statistics, 1990
FIRE employment	Gross employment in finance, insurance and real estate industries	CUPR, *State of the Nation's Cities*, 1999; US Department of Commerce, Bureau of Labor Statistics, 1990
Different residence	Percentage of households with different residence in 1990 than in 1985	US Census, 1990, summary tape file 3
Port tonnage	Gross annual tonnage of goods and cargo transported through maritime ports in the metropolitan area, 1990	Bureau of Transportation Statistics, US Department of Transportation and US Army Corps of Engineers statistics

From the CUPR database, a best-fitting model was estimated that predicted economic output per worker as well as two endogenously related variables, freeway density and city primacy (Table 2). Because these variables are jointly related, two-stage least-squares (2SLS) estimation was used to reduce simultaneous equation biases. Models were estimated in log–log (power function) form, thus coefficients can be interpreted as elasticities.

The empirical results generally match *a priori* expectations, although the two-stage model for predicting gross metro product per capita exhibited only modest explanatory power. A high location quotient of FIRE employment and an active freight port were found to be positively associated with economic output across the 47 cities. While, all else being equal, high employment densities increased productivity, suggesting the presence of agglomeration economies, the size of a metropolitan area did not enter as a reasonably significant predictor, reflecting an absence of urbanisation economies. This is consistent with the findings of Ciccone and Hall (1996) who showed, using county-level data across 20 US states, that density was more important than size in determining productivity advantages. In an advanced economy like that of the US, the findings suggest that the economic benefits of compactness and concentration outweigh the negative externalities.

Of particular note from the system of equations is that metropolitan areas with the

Table 2. Power-function model: 2SLS estimates of worker productivity, mobility levels and city primacy: 47 US metropolitan areas, 1990 (all variables in natural logarithmic form)

	Coefficient	Standard error	Probability
Dependent variable: GMP per worker			
Employment density	0.039	0.033	0.249
Freeway density	0.420	0.141	0.004
Port tonnage	0.047	0.043	0.289
FIRE employment	0.159	0.104	0.131
Constant	− 0.043	1.323	0.974
$R^2 = 0.473$			
$F = 9.642$; prob. = 0.0001			
$N = 47$			
Dependent variable: freeway density			
MSA population	0.115	0.037	0.003
GMP per worker	0.549	0.222	0.019
City primacy	0.124	0.066	0.061
Port tonnage	0.023	0.014	0.108
Different residence	0.706	0.181	0.000
Service employment	0.181	0.105	0.092
Constant	6.649	0.843	0.001
$R^2 = 0.689$			
$F = 18.567$; probability = 0.0001			
$N = 47$			
Dependent variable: city primacy			
City population	0.805	0.077	0.001
GMP per worker	2.138	0.483	0.001
Service employment	0.351	0.281	0.001
Constant	− 1.402	1.952	0.476
$R^2 = 0.757$			
$F = 33.577$; probability = 0.0001			
$N = 47$			

worst freeway congestion were also the best economic performers. Freeway congestion, of course, is mainly a product of economically active and vibrant cities. This was underscored during the recession of the early 1990s when traffic congestion disappeared from the list of most serious local problems among residents polled in many US metropolitan areas—nothing will do more to relieve traffic congestion (and eliminate commute trips) in the near term than mass lay-offs. However, contrary to what theory suggests, uncongested freeways, and thus higher travel speeds, did not work in favour of higher economic output across the 47 US metropolitan areas that were studied. Clearly, high employment density, which correlates positively with high economic performance, brings with it high levels of traffic congestion. And, more plausibly, causality is working in the opposite direction, despite the regression results—that is, good economic performance spawns freeway congestion as road capacity fails to keep pace with the growth in traffic (Downs, 1992). It could also be that metropolitan-level data mask the importance of congestion reduction in stimulating economic productivity; using county-level data from California, Boarnet (1997b) found that economic output rose as congestion levels fell. My finding might also reflect the peculiarities of an auto-dependent society like the US whose land-use patterns are predominantly market-driven. The negative externalities of traffic congestion along highways leading to areas of concentrated employment—be they downtowns or edge cities—are offset, one might infer, by the economic advantages of market-shaped urbanisation patterns. Such relations might not hold in land-constrained settings like Japan or the Netherlands. Kenworthy and Laube (1999) infer as much based on their analysis of global cities, showing that viable public transit systems, minimal car usage and high economic performance go hand-in-hand—underscored by the likes of Zurich and Stockholm.

Besides gross metro product, the 2SLS output shows that two urbanisation variables in particular—metropolitan population size and employment primacy—were positively associated with freeway congestion. So were variables measuring maritime port activity and fluidity in the local housing market (reflecting active in-migration to the community, thus rapid turnover in housing stock). A service-oriented economic base was also associated with densely trafficked freeways.

Lastly, the system of equations shows that city primacy—the share of regional jobs in the central city—was endogenously related to economic output. The regression model suggests that high productivity brings about employment agglomeration, especially in a service-based economy, even when controlling for population size.

While cross-city comparisons provide glimpses into core structural relationships between economic performance, size and agglomeration, the analysis is incomplete because of the absence of any direct measures of labour force accessibility or proximity. The micro-scale analysis that follows aims to overcome this shortcoming.

7. Micro-scale Analysis

Because of the data limitations faced in studying relationships at a cross-metropolitan scale, an analysis that used far richer metrics, but that was restricted to a single metropolitan area, was carried out. The unit of analysis was the 'super-district', a sub-county area of generally 10–15 square miles. The 9-county San Francisco Bay Area consists of 34 super-districts, as designated by the region's transport planning agency, the Metropolitan Transportation Commission (MTC) (Figure 1).

7.1 Labour Productivity Estimates

Computing labour productivity at a metropolitan level or below is problematic since the US Department of Commerce reports sub-national totals for economic output only at the level of states. The productivity index for any sub-area can be imputed by simple factoring, shown in equations 1–3: the statewide worker productivity index for SIC category c is multiplied by the number of workers in a super-district in category c, summed over all SIC categories to produce an estimate of total output for the super-district and then divided by the total number of workers in the super-district to yield an estimated productivity per worker (P_s).[3]

$$P_{ck} = O_{ck}/W_{ck} \tag{1}$$

$$P_{cs} = (P_{ck})(W_{cs}) \tag{2}$$

$$P_s = (\Sigma_c P_{cs})/W_s \tag{3}$$

where, P = productivity per worker index; O = economic output, in dollars; W = number of workers; c = employment classification category (for example, industrial classification); k = state (for example, California); and s = super-district.

7.2 Labour Market Size and Proximity

Two metrics of the effective labour-marketshed of a super-district—capturing information on both size and proximity of the labour pool—were computed: an isochronic measure; and, a gravity-based accessibility measure. The isochronic represents the effective labour market for any sub-area, $L(t)_s$, computed as a weighted average of the number of employed residents residing within t minutes of a traffic analysis zone (TAZ) within a sub-district, summed over all TAZs within the super-district (equation (4)).

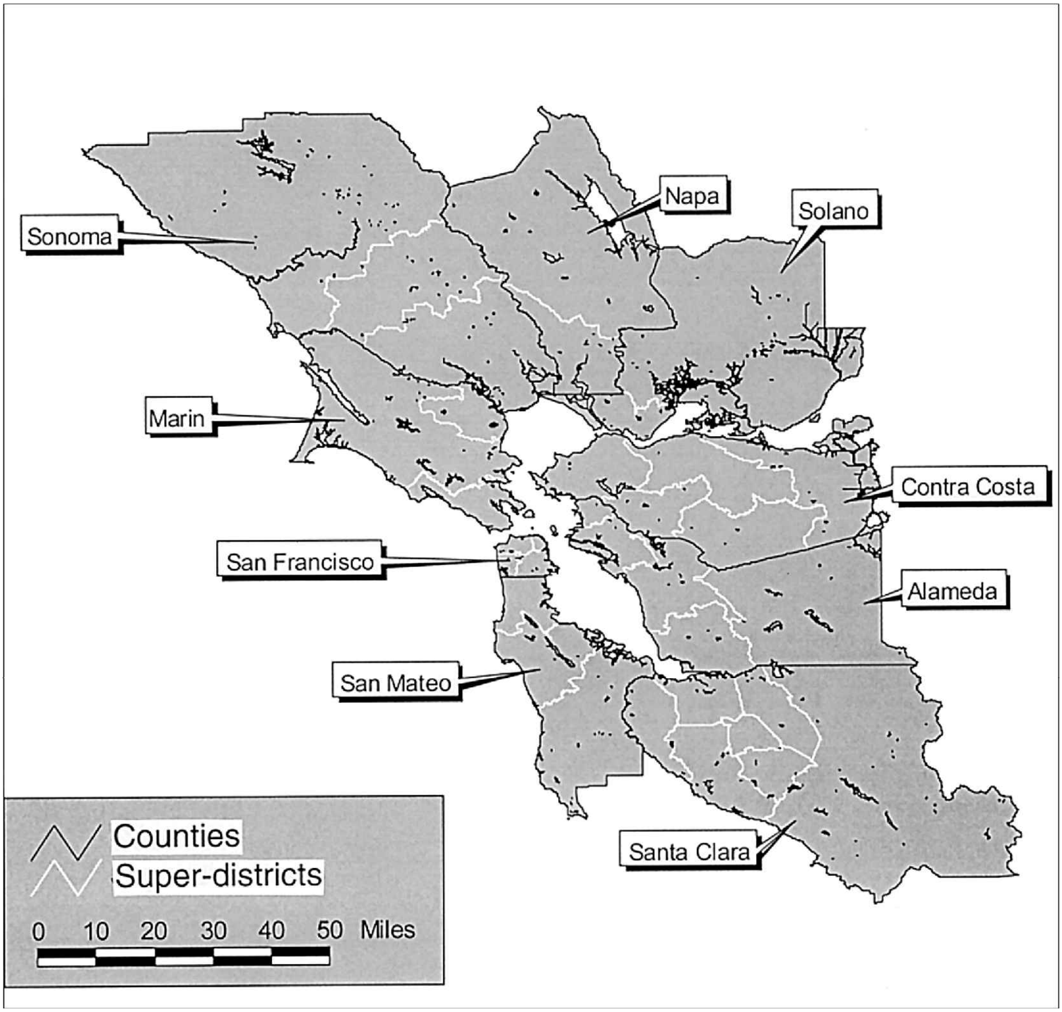

Figure 1. The nine counties of the San Francisco Bay Area and their super-districts.

TAZs, which typically comprise several census tracts, represent among the smallest geographical areas for which employment data are available; in the San Francisco Bay Area, most super-districts have between 30 and 50 TAZs. In computing numbers of employed residents within commute-time thresholds (of 30, 45 and 60 minutes), peak-period travel times over the highway network were calculated from the centroid of each TAZ within a super-district to the centroid of all TAZs within the travel-time threshold.[4]

$$L(t)_s = \Sigma_{sj}\{[\Sigma_i E(t)_i][W_{sj}/(\Sigma_{sj} W_{sj})]\} \quad (4)$$

where, $T_{i,sj} \leq t$

and $\Sigma_{sj} W_{sj} = W_s$

and where, in addition to previous definitions, $L(t)$ = effective labour market within t minutes; $E(t)$ = employed residents within t minutes; T = travel time, minutes: highway network, peak-period, TAZ centroid-to-centroid; t = commute-time threshold (30, 45, 60 minutes); i = origin TAZ—location of E (employed residents); and sj = destination TAZ—location of W (workers) within super-district s.

The second measure of labour force proximity—a gravity-based accessibility index—was computed using equation (5): the accessibility of any super-district s is based on cumulative counts of employed residents, modified by an impedance term $[\exp(-\gamma T_{i,sj})]$ and weighted by the share of total workers in any TAZ of a super-district to the total number of workers in the sub-district $[W_{sj}/\Sigma_{sj} W_{sj}]$.[5] For the San Francisco Bay Area, the impedance coefficient, γ, was set at–0.14 based on the best statistical fit for work-trip interchanges using a conventional transport trip distribution model.

$$A_s = \{\Sigma_{sj}[\Sigma_i E_i \exp(-\gamma T_{i,sj})] [W_{sj}/\Sigma_{sj} W_{sj}]\} \tag{5}$$

7.3 Commute Speeds

The primary index of mobility used in this analysis was commute speed. All things being equal, relatively high travel speeds reflect a well-functioning transport system and equate with high labour force accessibility. Equation (6) was used in computing average speeds for journeys to work to a super-district:

$$S_{ij} = (\Sigma_{sic} D_{sic,sjc})/(\Sigma_{sic} T_{sic,sjc}) \forall_j \tag{6}$$

where, in addition to previous definitions, S = mean commute speed, in miles per hour; D = highway network distance, in miles;[6] sic = centroid of TAZ i, TAZ centroid of origin super-district s; sjc = centroid of TAZ j, TAZ centroid of destination super-district s; and sj = super-district s, representing workplace destination j.

Thus, a super-district is assigned a mean peak-period speed based on the network distance to network travel time from the centroids of the TAZs that occupy the centres of each of the other 33 super-districts to the centroid of that super-district.

7.4 Data Sources

A database for the 34 super-districts was constructed for purposes of calculating metrics shown in equations (3)–(6) using data from the 1990 Census Transportation Planning Package (CTPP), Parts 1, 2 and 3, for the San Francisco–Oakland–San Jose Consolidated Statistical Metropolitan Area. Supplemental data on infrastructure and demographic characteristics of super-districts were compiled from STF-1A census files and GIS files on Bay Area transport infrastructure.

7.5 Spatial Patterns

In 1990, areas with relatively high levels of worker productivity were fairly evenly distributed across the Bay Area, as portrayed in Figure 2—notably, in the North Bay (Marin and Sonoma Counties), the East Bay (central Alameda and Contra Costa Counties), downtown San Francisco, central San Jose (in Santa Clara County) and the Peninsula (San Mateo County). (See Figure 1 for county locations.) Eastern parts of the region, which consist predominantly of bedroom suburbs with comparatively affordable housing, averaged relatively low levels of economic output per worker.

A convenient way to gauge the degree to which a variable like labour productivity follows a distinct spatial pattern and, specifically, how much it clusters, is to measure spatial autocorrelation. This was done using Moran's I statistic

$$\mathrm{I} = \frac{n \, \Sigma_i \Sigma_j \, w_{ij} \, (y_i - \bar{y}) \quad (y_j - \bar{y})}{[\Sigma_i \, (y_i - \bar{y})^2] \quad (\Sigma\Sigma_{i \neq j} \, w_{ij})} \tag{7}$$

where, y_i is the variable of interest; and w_{ij} is the spatial weight.[7]

A spatial autocorrelation of 0.255 was measured for worker productivity, indicating a modest degree of geographical clustering. Measures of labour-marketshed size (from equation (4)) were also positive spatially autocorrelated, with even stronger clustering than was recorded for the worker productivity variable: Moran's I statistic values ranged between 0.613 and 0.793 for labour-marketsheds defined within the ranges of 30–60 minutes.[8] Figure 3 shows that firms with the largest labour-marketsheds tended to be concentrated in the South Bay (San Jose and

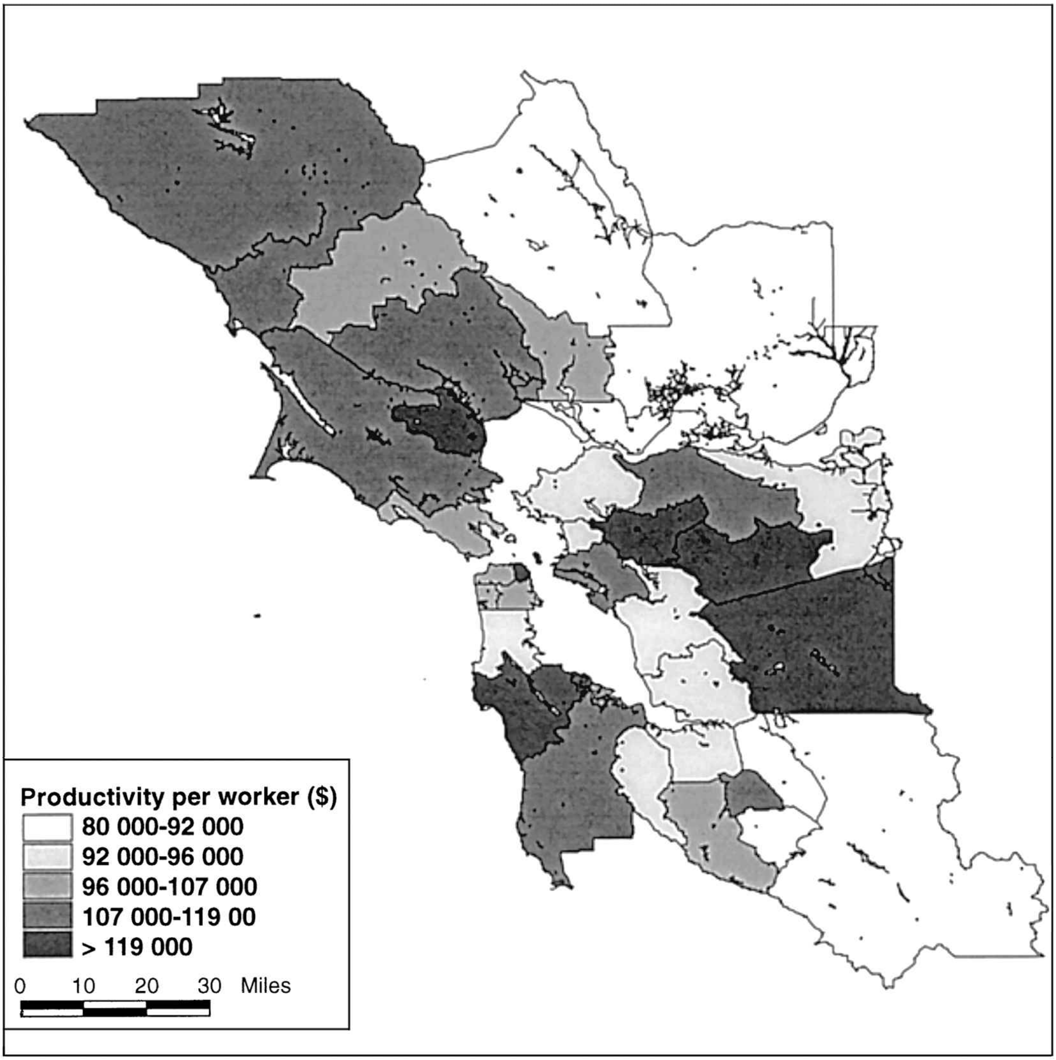

Figure 2. Mean productivity per worker in Bay Area super-districts, 1990.

northern Santa Clara County, home to the Silicon Valley), western parts of the East Bay, and the Peninsula (the northern part of San Mateo County, where the San Francisco International Airport is located). (Figure 3 is for the 60-minute travel catchment; relationships were similar for the 30-minute and the 45-minute catchments). In that these high labour-marketshed super-districts did not generally correspond to super-districts with the highest labour productivity (with some exceptions, like downtown San Francisco), one can surmise that the correlation between worker productivity and size of labour-marketsheds is likely to be fairly weak. The same thing can be inferred about the measure of labour market accessibility (equation (5)). This variable demonstrated a high degree of spatial clustering (a Moran's I of 0.792), but super-districts with the highest accessibility to labour were not always the most economically productive (Figure 4). This discordance was particularly notable in the case of super-districts in Santa Clara County. Thus, without even attempting to build a predictive model, simple spatial mapping casts some

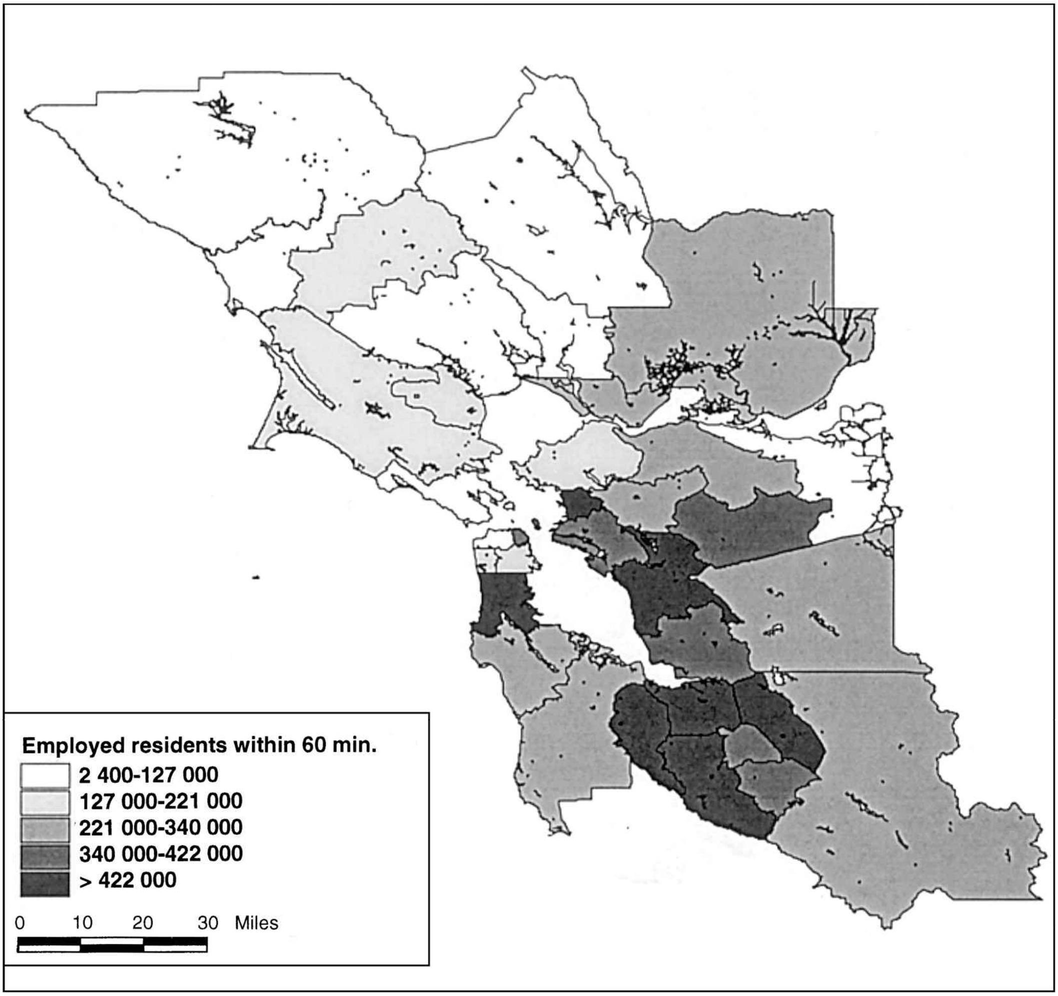

Figure 3. Sizes of labour-marketsheds: numbers of employed residents within 60 minutes of super-districts, 1990.

doubt on the statistical saliency of the research hypothesis when studied at an intrametropolitan scale.

A positive, albeit weaker, spatial autocorrelation (a Moran's I of 0.290) was found for the variable measuring mean commute speeds to employment destinations in super-districts (equation (6)). Expectedly, outlying super-districts generally averaged the highest average speeds (Figure 5). The slowest commute speeds were to jobs in the cities of San Francisco and San Jose. Lastly, the Bay Area has distinct spatial patterning with respect to land-use intensities: the Moran's I for population density (i.e. employed residents per acre) was 0.724 and for employment density it was 0.688.

Overall, fairly distinct spatial patterns of clustering were found for most of the core variables hypothesised as significant predictors of labour productivity. The tendency toward clustering in the Bay Area probably has something to do with the region's topography—hilly terrain and a large bay occupying the region's centre have restricted land supply, giving rise to more clustering of urban activities than is found in other US metropolises, such as in greater Los Angeles.

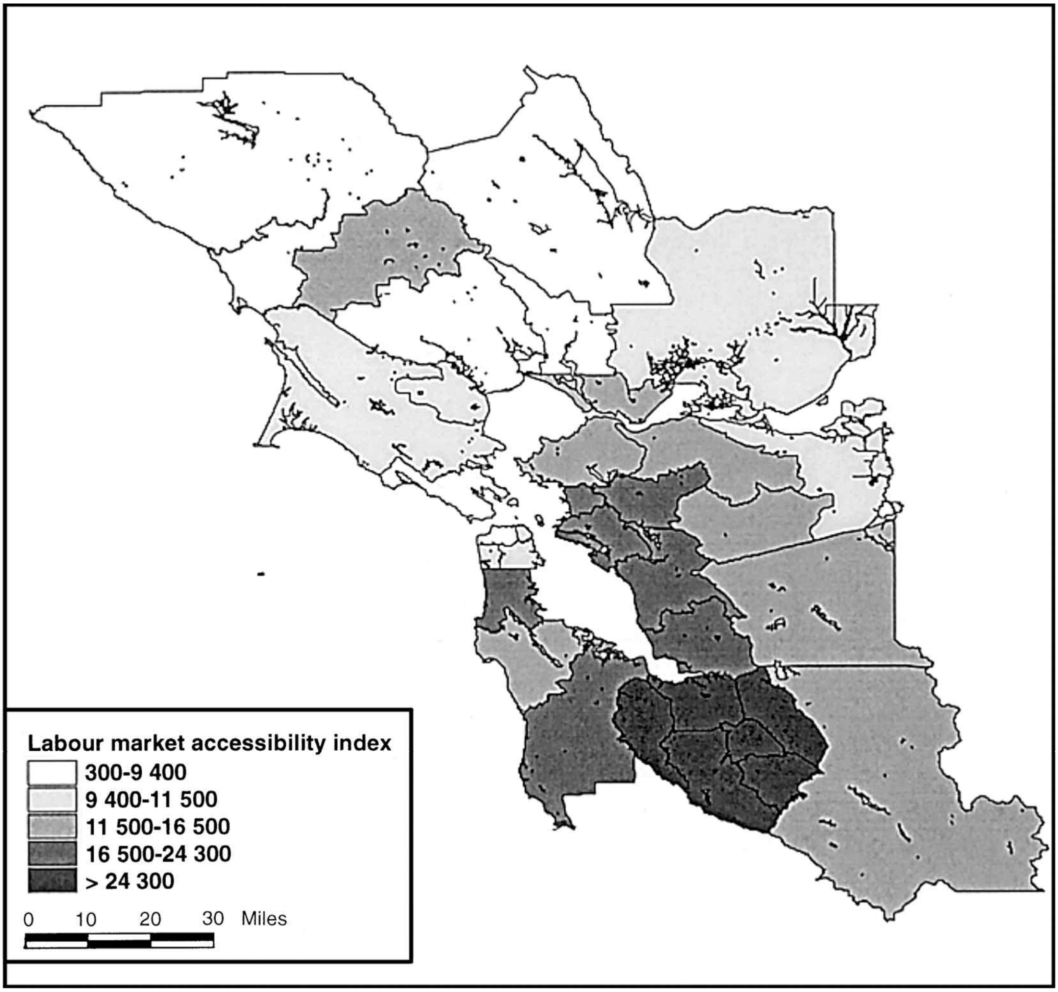

Figure 4. Sizes of labour market accessibility indices among super-districts, 1990.

It is also notable that from a pure visual scanning of GIS maps, there appears to be a weak correspondence between the hypothesised variables (size, accessibility and commute speed) and labour productivity. This could reflect the limitation of an intrametropolitan analysis or perhaps even the Bay Area's unique topography impeding the formation of a well-articulated, efficiently functioning labour market. In any event, these maps cast doubt over the prospects of capturing a strong statistical relationship among the variables of interest. Before presenting the results of this effort, however, let us further probe characteristics of core variables in simple descriptive statistical terms.

7.6 Descriptive Statistics

In 1990, the mean economic output per worker averaged across the 34 Bay Area super-districts was around \$106 000, with fairly modest variation around this average (Table 3). Of course, this figure significantly exceeded (by around a factor of 3) mean worker earnings in 1990, indicating shareholders and other owners of capital amassed much of the value-added from economic production—which is likely to have been all the

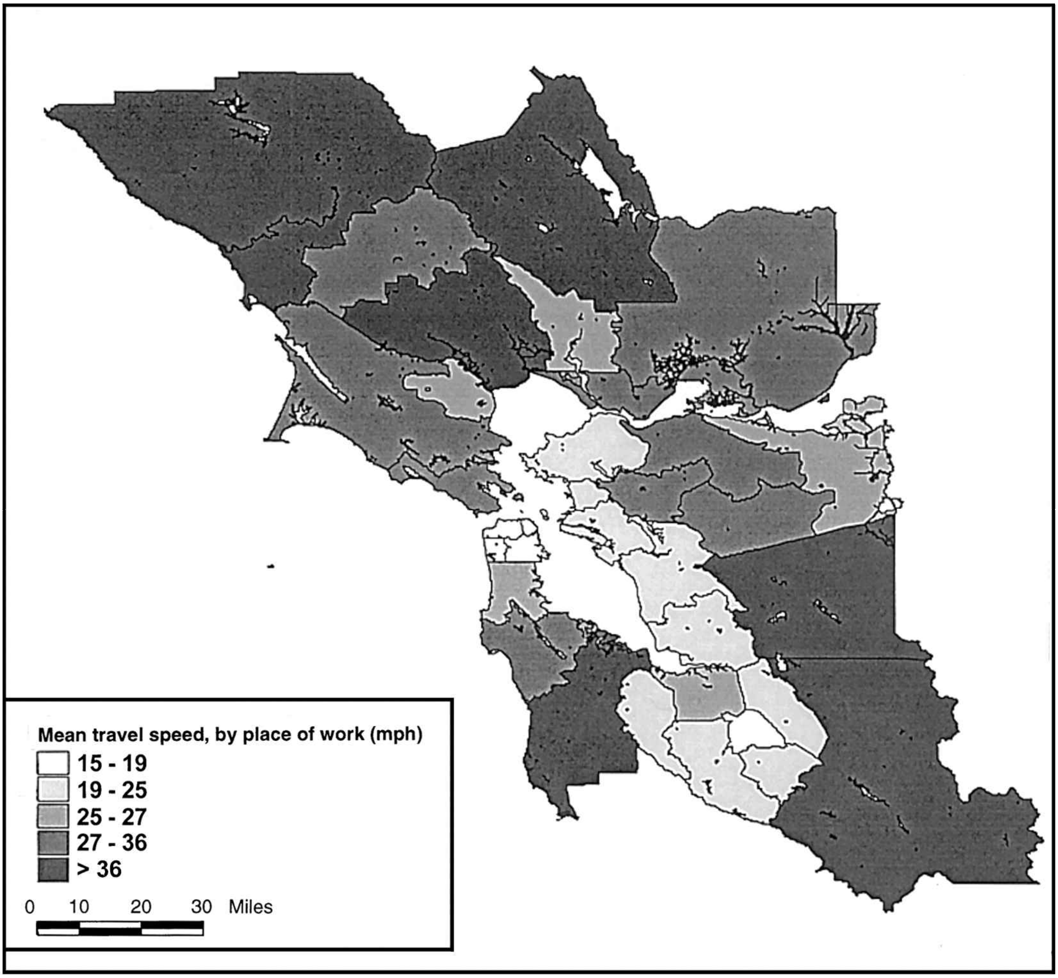

Figure 5. Mean travel speeds, by place of work, among super-districts, 1990.

more accentuated in a region like the San Francisco Bay Area, today an important global link in the rapidly emerging 'new economy' (Saxenian, 1994; Castells, 1996).

High worker productivity levels were recorded, as expected, in downtown San Francisco and in several East Bay super-districts containing edge cities with professional-class labour forces—namely, the Hacienda Business Park in Pleasanton and Bishop Ranch in San Ramon. Surprisingly and somewhat disconcertingly, labour productivity levels, as measured, were fairly low for super-districts in Santa Clara County, including the Silicon Valley. This is felt to be an artifact of how worker productivity was calculated. It is likely that per worker output for the many high-technology industries comprising the Silicon Valley is understated by the use of state-wide productivity levels for those same industries, as expressed in equation (1). That is, labour productivity is thought to be considerably higher in high value-added high-technology industries than what is captured for those industries in corresponding two-digit standard industrial classification (SIC) codes throughout the state of California. This measurement problem is felt to be serious enough to compromise the predictive modelling of

Table 3. Descriptive statistics of core variables

	Mean	Standard deviation	Minimum	Maximum
Mean productivity per worker ($)[a]	105 900	17 520	80 400	155 600
Labour-marketshed[b]				
30 minutes	174 400	109 205	6 435	451 780
45 minutes	243 430	149 660	6 560	642 620
60 minutes	282 260	168 025	6 720	718 745
Accessibility index[c]	16 510	9 460	325	36 965
Mean commute speed (mph)[d]	27.58	8.94	15.89	57.10
Employees per gross acre	4.81	15.87	0.003	93.25
Population per gross acre	5.85	8.37	0.088	36.00
Employed residents per gross acre	3.04	4.37	0.041	0.156

[a] Computed using equations (1)–(3).
[b] Number of workers within the defined peak-period, network travel time of a super-district. Computed using equation (4).
[c] Computed using equation (5).
[d] Mean peak-period, network travel time to a super-district as a place of work. Computed using equation (6).

relationships, calling for the removal of super-districts in Santa Clara County from the analysis.

Table 3 also summarises spatial statistics on relative proximity to and accessibility of labour markets in the San Francisco Bay Area. At the super-district level, on average there were around 175 000 employed residents within a 30-minute peak-period commute over the highway network; doubling this to a 60-minute commute threshold increased this average figure by 61 per cent, or to about 282 000 workers. Super-districts comprising the Silicon Valley in central and northern Santa Clara County had the largest number of workers within commuting distance (around 643 000 for the 45-minute threshold); far north-west Sonoma County had the fewest employed residents within commute 'striking distance'. While metrics for the accessibility index (i.e. cumulative job opportunities adjusted for travel-time impedance) do not have much intuitive meaning, similar kinds of relationships (in terms of variation and spatial patterns of low and high scores) were found as with the labour-marketshed variables.

Table 3 also shows that the average commute speed in 1990 to jobs in super-districts was almost 28 mph, ranging from around 16 mph (to downtown San Francisco jobs) to as high as 57 mph (for jobs on the fringe). This region-wide estimate is in line with the average of 26 mph for auto commuters estimated by the Metropolitan Transportation Commission (Purvis, 1994) as well as the national average estimated in 1990 for central cities (24.8 mph) and suburban parts of metropolitan areas (33.4 mph) (Pisarski, 1992).[9]

Lastly, several statistics on gross densities are summarised for the 34 super-districts in 1990. The high degree of variation is most notable in these statistics, particularly in the case of employment density, ranging from extremely low densities in the fringe areas of the North Bay to very high ones in the city of San Francisco.

7.7 Predictive Model

The hypothesis that proximity, accessibility and speed positively influence labour productivity was tested at the super-district level. Because of the suspicious estimates of labour productivity in the high-technology-oriented South Bay, the 7 super-districts in Santa Clara County were purged from the analysis. The remaining 27 super-districts comprised

Table 4. Labour-marketshed model: OLS estimates of worker productivity in the San Francisco Bay Area, exclusive of Santa Clara County super-districts, using three different travel-time sheds (all variables in natural logarithmic form; dependent variable: mean productivity per worker)

	Travel-time shed					
	30 minutes		45 minutes		60 minutes	
	Coefficient	Probability	Coefficient	Probability	Coefficient	Probability
Labour-marketshed	0.068	0.191	0.078	0.123	0.085	0.096
Average commute speed	0.104	0.220	0.099	0.236	0.110	0.179
Employees per acre	0.057	0.024	0.054	0.033	0.053	0.036
Percentage of workforce white	0.758	0.006	0.767	0.005	0.767	0.004
Constant	−3.052	0.000	−3.186	0.000	−3.308	0.000
R^2	0.484		0.502		0.511	
F statistics	4.781		5.112		5.313	
Probability	0.007		0.005		0.004	
Number of cases	27		27		27	

the 8-county San Francisco–Oakland Metropolitan Statistical Area as defined by the US Census Bureau.

As noted earlier, two measures of labour market size and proximity were computed: an isochronic measure of labour-marketshed (equation (4)) and a gravity-based measure of labour accessibility (equation (5)). Because these metrics were highly co-linear, two sets of models were estimated: one measuring labour-marketshed for three sets of travel-time thresholds and the other using the labour accessibility index. Supplementing these variables were measures of average commute speeds and an indicator of land-use intensities. A demographic variable, representing racial compositions of workforces, was used as a statistical control variable. Other potential controls—notably, centre-lane miles of freeway and urban-rail track-miles of service—were also candidate variables, but did not enter any of the models because of poor statistical fits.

Table 4 presents best-fitting models using labour-marketsheds to represent labour force scale and proximity. For all sets of models, estimated coefficients are consistent with expectations; except for the demographic control and employment density variables, none of the other predictors is statistically significant at the 0.05 probability level. Still, the models explain around half the variation in mean productivity per worker in all cases.

Among the policy variables shown in the table, average commute speed—reflecting the provision of transport infrastructure—most strongly influenced labour productivity in the San Francisco Bay Area, with an elasticity of around 0.10—every 10 per cent increase in commuting speed was associated with a 1 per cent increase in worker output, all else being equal. It is noted that this relationship is the opposite of that found for the macro-scale analysis. These are not necessarily contradictory findings, however. It could very well be that while across regions, congested freeways and slow commute speeds are a by-product of economically vibrant areas, within metropolitan areas, sub-areas with better-performing highways enjoy economic advantages, and perhaps high value-added companies outbid others for the choicest, freeway-served locations. This is an area worthy of further research exploration.

Influences of urban-form variables on labour productivity were generally fairly weak, with elasticities in the range of 0.05 to 0.08. Super-districts with larger labour markets averaged relatively high levels of econ-

Table 5. Labour accessibility model: OLS estimates of worker productivity in the San Francisco Bay Area, exclusive of Santa Clara County super-districts (all variables in natural logarithmic form; dependent variable: mean productivity per worker)

	Coefficient	Standard error	Probability
Accessibility index	0.059	0.054	0.262
Average commute speed	0.121	0.243	0.154
Employees/acre	0.062	0.023	0.016
Percentage workforce white	0.763	0.249	0.008
Constant	− 2.868	0.558	0.000
R^2	0.466		
F statistic	4.490		
Probability	0.009		
Number of cases	27		

omic output, all else being equal, although again the relationship was not statistically significant at the 0.05 probability level. Table 4 does suggest that the relationship strengthened as the definition of labour-marketshed expanded. Defining labour-marketshed within a 60-minute travel-time band was associated with a 25 per cent higher increase in labour productivity relative to a 30-minute travel-time definition, *ceteris paribus*. This finding supports the contention that 'bigness' promotes productivity by enlarging the labour-marketshed and argues in favour of the use of a larger commutershed by transport and economic development planners when defining the functional boundaries of metropolitan areas like the San Francisco Bay Area.

Coefficients on the employment density variable in Table 4 suggest that agglomeration economies favour higher economic output. Consistent with the finding that urban primacy was positively associated with productivity in the macro-scale analysis (from Table 2), super-districts with higher employment densities were found to enjoy higher economic output in the micro-scale analysis. While the elasticities on the employment density variable were lower than those for speed and labour-marketshed, employment density was the only policy variable statistically significant at the 0.05 probability level.

Modelling relationships using the alternate measure of labour market size and proximity—i.e. the accessibility index—produced the results shown in Table 5. In general, the relationships were quite similar when expressed in this form. The elasticity on the accessibility variable (0.059) was slightly lower than the lowest elasticity among the three isochronic measures of labour-marketshed—0.068. Thus, the isochronic measures outperformed the accessibility index in predicting labour productivity, albeit only slightly so. Elasticities for other predictive variables were generally slightly higher in the accessibility index model. Again, only the demographic and employment density variables were statistically significant at the 0.05 probability level; however, the overall model was significant and explained nearly half the variation in productivity per worker.

Overall, the micro-scale analysis yielded results that were consistent with theory and that confirmed and reinforced the findings from the macro-scale analysis. While interregional differentials are thought to shape productivity more strongly than intraregional ones, nevertheless many of the same mechanisms that govern how urban form and transport investments influence economic outcomes appear to be at play within metropolitan areas as well.

8. Conclusions

Much remains to be learned about how physical attributes of cities and regions influence economic performance. Despite a dearth of empirical evidence, fairly strong positions have been taken over the years on preferred physical patterns of urbanisation—whether in the form of first-world urban growth boundaries or third-world decentralisation programmes. The broader economic productivity implications of such urbanisation policies tend to take a back seat to more immediate and parochial concerns related to fiscal cost-containment and open-space protection.

The findings from this research suggest that the urban form and mobility characteristics of metropolitan areas have some bearing on economic performance, as theorised by Prud'homme and others. Specifically, urban size, proximity of co-dependent activities and commuting speeds appear to 'matter'. All else being equal, bigger areas with large laboursheds, good accessibility between jobs and housing, and well-functioning transport systems appear to enjoy some economic advantages. While from a statistical standpoint, the relationships uncovered in this research were not terribly strong, the findings were sufficiently suggestive to warrant more in-depth empirical investigations into this policy area.

The results of both the macro-scale and micro-scale analyses presented in this paper were generally consistent. At both grains of analysis, employment densities were positively associated with productivity levels, suggesting the presence of agglomeration and urbanisation economies. Employment clustering was reflected by high positive spatial autocorrelations. The macro-scale analysis also uncovered a positive association between labour productivity and urban primacy. It was at the intrametropolitan scale of analysis that refined metrics of labour-marketsheds and labour-accessibility indexes were developed. These metrics performed perhaps as well as might be expected in predicting labour productivity given that intrametropolitan analyses of labour productivity are compromised by the fact that regional forces largely shape economic outcomes. Statistically, the elasticities between labour productivity and both labour-marketshed size and labour accessibility were fairly small and were not highly significant. However, if such metrics were available across many metropolitan areas, it might be expected that the elasticities would be considerably higher when measured with an intermetropolitan statistical model.

The findings of this paper shed light on several other aspects of the relationship between urban form, transport services and economic productivity. One, the effects of labour-marketshed size on productivity were greater for larger, more liberally defined catchment areas. In a region like the San Francisco Bay Area, this could reflect the impact of shortages of affordable housing that displace tens of thousands of moderate-salaried workers to the exurban fringes and rural hinterlands (see Cervero and Wu, 1997). In a high-cost housing market, it is plausible that workers are willing to endure longer commutes in return for suitable housing on the fringes, enabling firms to draw upon specialised skills and diverse labour inputs over large catchment areas. Transport planners often use 30–45-minute commute times as a normative definition for a commutershed, based on time-budget theories (Grubler, 1990; Hupkes, 1982). The stronger relationship between 1-hour laboursheds and economic output uncovered in this research suggests that a more liberal definition of commutersheds for transport planning purposes might be in order. Secondly, this research revealed somewhat peculiar relationships between economic performance and roadway conditions. Across metropolitan areas, more crowded freeways appear to be a consequence, in part, of rapid economic growth. Accordingly, an inverse statistical relationship between average travel speeds and productivity levels was found. However, the intrametropolitan analysis suggests that sub-areas with better infrastructure, and thus higher average speeds, do out-perform other sub-areas, all else being equal. One might surmise that while indeed better transport contributes to better economic performance, inertia—whether in the form of institutional lags, fiscal constraints or community resistance—many times delays investments in highway infrastructure sufficient to keep pace with growth. To the degree this is true across metropolitan areas, then worsening traffic congestion is a predictable outcome, particularly in fast-growing areas. This has been the case throughout much of the US over the past two decades (Schrank and Lomax, 1999).

The empirical results of this study hopefully are of some value to contemporary debates regarding preferred patterns of urbanisation. At minimum, it is hoped such analyses can help balance the skewed attention given to the cost side of alternative urbanisation patterns, bringing some aspects of benefits into the equation. While this research augments findings of others who have studied these relationships in first-world and newly industrialised contexts (i.e. the work of Prud'homme and Lee, 1999), how these relationships hold in a developing-country context remains largely unknown. Indeed, the potential value-added of empirically investigating these relationships in rapidly developing countries like Indonesia, China or Brazil is likely to be even greater. Of course, the obstacles to studying empirically how urban form influences economic performance in the developing world are huge, with access to reliable data inputs heading the list. Econometric approaches might have to give way to a balance of qualitative case studies and quasi-statistical analyses in investigating these relationships in developing countries. This remains an area where follow-up research is very much needed.

Notes

1. The following MSAs comprised the database used in this analysis, expressed in terms of the primary city or cities of each MSA: Albuquerque, Atlanta, Austin, Baltimore, Boston, Charlotte, Chicago, Cincinnati, Cleveland, Columbus, Dallas, Denver, Des Moines, Detroit, El Paso, Fort Worth, Hartford, Honolulu, Houston, Indianapolis, Jacksonville, Kansas City, Los Angeles–Long Beach, Louisville, Memphis, Miami, Milwaukee, Minneapolis–St Paul, Nashville, New Orleans, New York City–Newark, Norfolk–Virginia Beach, Oakland, Oklahoma City, Philadelphia, Phoenix, Pittsburgh, Providence, Portland (Oregon), Sacramento, St Louis, Salt Lake City, San Antonio, San Diego, Seattle, Tampa–St Petersburg, Washington, DC.
2. Data on numerous other variables were also compiled; however, only those which proved to be significant predictors, and which are shown in Table 2, are listed in Table 1.
3. SIC stands for Standardised Industrial Classification, as defined by the US Department of Commerce.
4. A possible biasing effect is that the labour-marketsheds of outlying super-districts are underestimated since territories outside the nine-county Bay Area are not incorporated into the analysis by using solely the Bay Area CTPP. This effect was negated by including data for census 'places' (which generally correspond to municipalities) in calculating labour-marketsheds for the surrounding counties that flank or lie beyond the Bay Area: Santa Cruz, Monterey, San Benito, Merced, Stanislaus, San Joaquin, Sacramento, Yolo, Lake, Colusa, Mendocino. The statewide CTPP was used to acquire worker and employed-resident data for the non-Bay-Area municipalities.
5. As outlined in note 4 above, municipal-level data for counties outside the nine-county Bay Area were used for estimating accessibility indices for peripheral super-districts.
6. Trip distances were estimated by skimming over link files of the Bay Area's highway network using the TransCAD transport-GIS software package.
7. Moran's I was calculated using the TransCAD GIS software package. The weight, w_{ij}, was based on the degree of 'shared-boundary' adjacency of super-districts, ranging in value from 0 (non-adjacency) to 1 (only when one super-district totally envelops another, which is not the case with Bay Area super-districts). Like a Pearson product moment correlation, Moran's I ranges in values between -1 and $+1$, with a high positive value indicating spatial clustering and agglomerations, a high negative value revealing a 'patchy', alternating spatial pattern, and a 0 value suggesting pure spatial randomness.
8. Specifically, Moran's I correlations were: 0.793 for the 30-minute labour-marketshed; 0.700 for the 45-minute labour-marketshed; and 0.613 for the 60-minute labour-marketshed. Thus, more clustering was recorded when labour-marketsheds were measured in 'tighter' half-hour time-bands.
9. A work-trip speed estimate for the San Francisco Consolidated Metropolitan Statistical

Area (CMSA) is also available from Gordon and Richardson (1995) based on 1990–91 data from the National Personal Transport Survey (NPTS): 29.6 mph inside the central city (San Francisco) and 33.9 mph outside the central city (elsewhere in the region). Given that this includes all modes of travel, including commutes by mass transit, this estimate seems to be on the high side when compared to the MTC estimate, possibly due to the relatively small sample size available from NPTS for any single CMSA.

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