Changes in Population Distribution and Automobile Ownership and Implications for Urban Transportation

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Emergent long-term trends in population and automobile ownership are examined, and some implications for urban transportation are drawn. Population trends include (a) a strong national trend toward zero population growth, at a pace well above demographers' expectations; (b) an inverse relation between growth and urban size, where the largest metropolitan areas exhibit little or even negative growth; and (c) a general shift in population from higher to lower density areas, with associated lower congestion, and some reversal of migration flows from nonmetropolitan to metropolitan places. Statistical analysis of growth rates shows two key relations: high rates of growth in three subregions (Pacific Southwest, Florida, and middle-sized Texas areas) and an inverse relation between size and growth for both the high-growth and low-growth areas of the country. Despite the continuing shift of population from central cities to suburbs, available evidence suggests some current diminution of suburban sprawl and a likely buildup of population densities in urban areas, a development that can be related to a corresponding movement toward saturation of automobile ownership. Data on intraurban density relations and rates of automobile ownership are presented in support of these predictions. The discerned trends in population and automobile ownership are likely to reduce traffic congestion and hence the needed highway investment and improve the viability of public transit in the large urban areas investing in such systems.

The apparent slowdown in population growth and the population shifts from more congested to less congested areas should relieve traffic congestion and reduce transportation requirements. The movement toward saturation of automobile ownership implies a ceiling on highway requirements but may involve higher urban densities, particularly in less congested areas. Higher densities, however, could make public transit more viable.

Nationally, there is a strong trend toward zero population growth (ZPG); recent birth rates are below replacement levels. At the same time, there has been very slow or even negative growth in large metropolitan areas, the areas of greatest congestion. Between 1970 and 1973, five of the 15 largest metropolitan areas experienced declines in population, and, of the rest, only Washington, D.C., grew as much as 3 percent, the national growth rate. In light of these trends, it may not be too long before the concern is with population shortages.

Not only has there been a shift from the more congested to less congested areas, but also, at the regional level, there is a long-term shift from the northeast and north central regions to the south and west. Three of the fastest growing regions are Florida, middle-sized Texas areas, and the Pacific Southwest, exclusive of Los Angeles and San Francisco. Not only are large areas growing slowly, but also there is a statistically significant inverse relation between metropolitan size and growth rate. The relative shift toward nonurban areas is not the major reversal of historic migration streams that some see it as, for much nonurban growth occurs just outside metropolitan boundaries.

These movements from more congested to less congested places are no mere coincidence. I see long-term equilibrating mechanisms at work, wherein people are moving to places that yield higher real income or general well-being (not necessarily measured in economics). A major component of the higher real income is traceable to less congestion and corresponding decreases in driving and time costs, air pollution, and noise. Admittedly, the destination areas become more congested and polluted with the inflow of migrants, but the system as a whole gains. The benefits at the origin, and to people moving from the origin, should outweigh the costs to those at the destination.

There is some empirical evidence supporting the movement toward saturation of automobile ownership and an end to urban sprawl, but the thesis here also depends on the argument explaining intraurban distribution of population. Population density within urban areas shows steady decline from the center. This distance-decay relation can be explained by the access-space trade-off or, put another way, by the trading of travel time for rent. Changes in this density relation can be tied to (a) population change and (b) the extent of the highway network and car ownership.

The larger the city is, the greater the density at any distance from the center is. As an urban area grows, land values go up, causing more intensive land use and greater density at all points. Congestion effects near the center inhibit growth there and encourage growth near the periphery. As reliance on the automobile increases, i.e., as roads and automobile ownership increase, density near the center decreases and population spreads out farther (or sprawl occurs). For example, the newer cities in the west, Texas, and Florida were built with the automobile in mind and are much less dense than older cities in the east. In recent history the impact of population change has been dominant over changes in the highway network and car ownership, but the latter are likely to become much stronger in the future, as areas approach automobile saturation. Thus, changes in the density relation for Baltimore show continued dominance of the second factor from 1960 to 1970 and from 1950 to 1960, whereas five western cities show the "sprawl" shift dominant only from 1960 to 1970 and some signs of a building up of density from 1950 to 1960. In 1970, Baltimore's density pattern roughly paralleled that of Los Angeles 2 decades earlier. Density data on a number of cities in specific time periods support the pattern of change discerned here. Additional support comes from analyses of automobile ownership data. Over time, the percentage of multiple-car families as a function of income has increased, which indicates suburbanization. This increase reached a peak in 1963-1966 and then slowed substantially, and it can be hypothesized that the pace of suburbanization moved in the same fashion. Reduction of air and noise pollution level should counteract some of the inhibition of growth near the urban center and higher energy prices should reinforce the pattern, making cities more dense and further limiting sprawl.

Analyses were made of automobile ownership rates; the equations developed can be used to forecast car ownership for specific years. Such forecasts would indicate how fast we are approaching "ultimate" saturation levels. In 1971, there were 1.15 cars per household, and available data indicate an ultimate level of 1.75 cars per household, an increase of 52 percent. Given alternative ZPG forecasts, ultimate levels for total car ownership can be projected as 2.0 to 2.3 times present levels, which seems hardly overwhelming.

With slow population growth and a movement toward saturation of automobile ownership, there should be a slowdown in demand for new highways. Density increases, particularly in fast-growing urban areas, should make public transit more viable, though probably not economic in the sense of covering costs.

Almost all of these trends are beneficial, for they should reduce the pressure for solutions to transportation problems considerably.

DEMOGRAPHIC TRENDS

Total Population

Since 1960, annual population growth in the United States has shown a steady decline, from about 3 million in 1960 to half that in 1970. There was some reversal of the trend in the period 1968-1970, but the decline was reestablished thereafter (Fig. 1).

If we mechanically fit a trend line to the data in Figure 1 by least squares, we reach ZPG in short order. A linear fit yields a ZPG date of 1989, whereas a logarithmic function, with a bit more variance explained, moves the date to 1993. The respective equations are

$$\Delta P = 2{,}425.8 - 101.5\ T \qquad \bar{R}^2 = 0.88,\ \text{t-ratio} = 10.5 \tag{1}$$

and

$$\Delta P = 30{,}543.7 - 15{,}515.8\ \text{LOG}\ T^* \qquad \bar{R}^2 = 0.89,\ \text{t-ratio} = 10.6 \tag{2}$$

where

ΔP = annual population change,
T = YEAR-1965, and
T^* = YEAR-1900.

Maximum population is only 226 million based on a January 1974 population of 211 million. The mechanical fit is a limiting case, of course. Because of the large number of women of child-bearing age, a consequence of the post-World War II baby boom, it is plausible that the downtrend will taper off.

Recognizing the trend, the Bureau of the Census has substantially reduced its population projections (2). Yet there are indications that the bureau has not gone far enough. In previous projections, the average number of births per woman upon completion of child-bearing was alternatively set at 3.1, 2.8, 2.5, and 2.1 to yield projections respectively labeled the B, C, D, and E series. Late in 1972, the bureau dropped the B series and added an F series, which assumed 1.8 births per woman. For the year 2000, the midpoint population projection for the initial set of alternatives was 296 million; for the revised series, the midpoint projection is 275 million. The E series corresponds to eventual ZPG, 2.1 births per woman. If that level holds indefinitely, population will be 264 million in the year 2000 and will stabilize at 320 million around the year 2025. But actual experience in 1972 and 1973 (Table 1) is best represented by the F series.

The Bureau of the Census (1) made the following growth predictions (in millions) for June 30, 1972, to July 1, 1974:

Series	Growth
C	4.5
D	4.2
E	3.3
F	3.0

In the F series, projected annual growth first increases to 1.8 million and then declines to around 1 million by the year 2000 at a total population of 250 million; a peak population of 270 million is reached by 2020. Thus, the F series decline is not nearly so drastic as that obtained by straight-line projections; nonetheless, it represents a considerably reduced rate of growth relative to recent expectations.

Given oral contraceptives and abortion on request, a marked reversal of the trend seems unlikely. In retrospect, the furor over ZPG in the U.S. context seems somewhat surprising in the light of the downtrend shown in Figure 1. Perhaps both ideology (ZPG enthusiasm) and mores (changing life-styles) follow technology (improved birth control).

The deceleration in population growth has led to overcapacity in pediatrics and elementary education, and similar problems are conceivable in transportation capacity. However, the considerable lag between birth and trip-making should provide enough lead time to adjust transportation planning to changed circumstances. It must be added that the reduced birthrate may allow more women to enter the labor force and thus increase trip-making for a considerable period. The increased number of working women has increased the number of journeys to work, and for many families the additional income has made a second car feasible. It has been suggested, in fact, that working women are the major cause of the last decade's increased energy demand (3).

Population Distribution

Concern about population distribution generally focuses on urban growth and the possibility that cities are too large. Here again, trends appear to be preempting the problems. The trends include (a) little growth or even declines in population in the largest metropolitan areas; (b) an inverse relation between growth and size; (c) a continuation of shifts from northeastern and north central urban areas to those in the south and west; (d) continuation of the shift from central cities to suburbs; but (e) some apparent reversal of migration flows from nonmetropolitan to metropolitan areas.

The census estimate that, between March 1970 and March 1973, there was a net flow of around a million people from SMSAs to places outside of SMSAs has been viewed by some as a major turning point (4). The statistic is a bit misleading because it disregards the location pattern of 2.4 million people who moved to the United States from abroad. Most of these people settled in metropolitan areas, which countered the internal migration shift somewhat. Detailed information on these migration flows is given in Table 2, which shows where the population in 1970 was located in 1973. The table does not include births since March 1970.

The percentage distribution of the population in the two periods was as follows:

Location	March 1970	March 1973
Central cities	32.20	30.21
Remainder of SMSA	36.69	38.34
Outside of SMSA	31.11	31.45
	100	100

The increase for the nonmetropolitan percentage contrasts with a previous long-term decline. Thus, between 1960 and 1970, the nonmetropolitan population as a percentage of the total declined from 33 to 31 percent (6).

If we accept the estimated March 1970 and March 1973 percentage distributions as given and apply them to estimated total resident populations for the respective periods, we obtain the following estimated distributions of number of people (in thousands):

Figure 1. Annual U.S. population growth from 1960 to 1973 and fitted trend line.

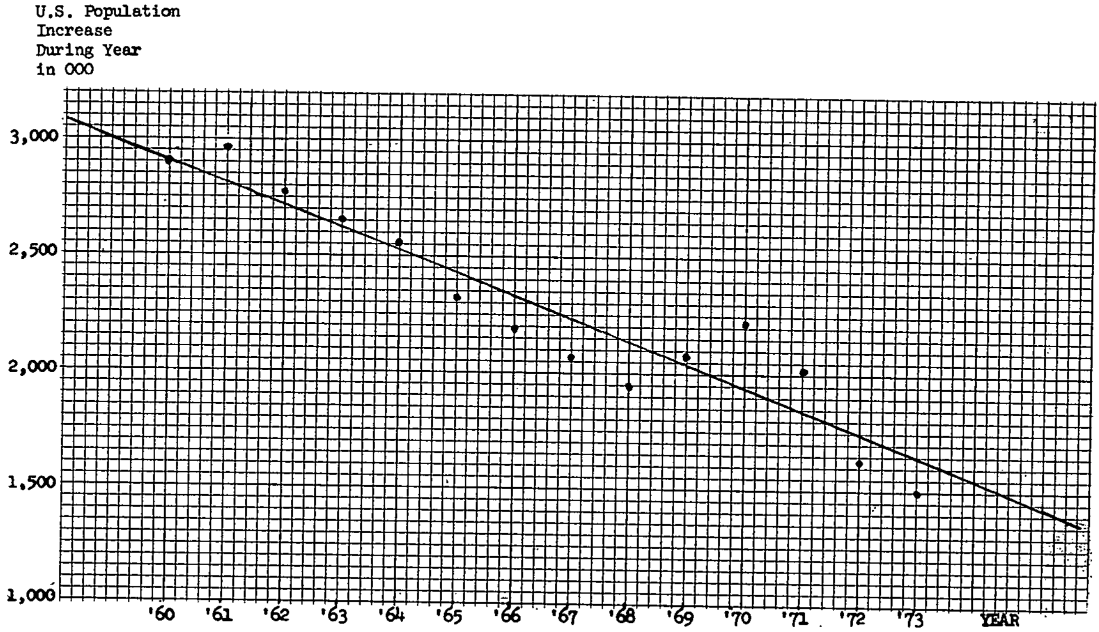

Table 1. Annual U.S. population.

Year	Population Growth[a] (in thousands)	Year	Population Growth[a] (in thousands)
1960	2901	1967	2072
1961	2955	1968	1952
1962	2771	1969	2089
1963	2655	1970	2223
1964	2555	1971	2017
1965	2316	1972	1628
1966	2197	1973	1499

[a]Includes armed forces overseas.

Table 2. Distribution of the U.S. population (in thousands) in 1970 and 1973.

				Population in March 1973			Net Flows	
Location	Population in March 1970	Movers	Nonmovers	Central City	Remainder of SMSA	Outside SMSA	Excluding Movers From Abroad	Including Movers From Abroad
Central city	62,333	25,197	37,136	52,927	7,278	2,128	-4,124	-3,112
Remainder of SMSA	71,042	22,922	48,120	3,673	64,704	2,665	3,209	4,114
Outside SMSA	60,225	20,525	39,700	1,609	2,269	56,347	915	1,431
Outside U.S.	2,433	2,433		1,012	905	516		
Total in 1973	196,033	71,077	124,956	59,221	75,156	61,656	0	2,433

Location	March 1970	March 1973	Ratio 1973/1970
Central cities	65,394	63,239	0.967
Remainder of SMSA	74,513	80,257	1.077
Outside of SMSA	63,180	65,834	1.042
	203,087	209,330	1.031

(This distribution accounts for births since 1970.) The central cities declined in total population by 3.3 percent, whereas the remainder of SMSAs grew faster than the remainder of the country (7.7 versus 4.2 percent). These percentages contrast with respective percentage growth between 1960 and 1970 of 5.3, 28.2, and 6.5 for the three locales. The increase in central city population in the 1960-1970 period may well reflect annexations rather than growth within city limits as defined in 1960. (Cities that annexed no territory showed a small population decline in the period.) Hence, the decline in central city population can be viewed as a continuation of earlier trends. However, the relative shift to nonmetropolitan areas seems substantial; if it is not a reversal of earlier trends in population growth, it does represent a considerable shift in relative strength of those trends.

Much of the nonmetropolitan growth probably involves a form of urbanization, and reflects (a) growth in the "far suburbs" around existing metropolitan centers but outside the county lines defining SMSAs, (b) development of industrial complexes at intersections of major highways at some distance from metropolitan areas, and (c) expansion of service industry employment in rural counties (7, 8). In all cases, improved highway transport is probably a major underlying cause for the shift.

Beale (9) argues that there has been a narrowing of life-style differences so that "urban areas are not as urbane as they were" and "rural areas are not as rustic" and that this is an additional reason why more people remain in nonmetropolitan areas. Although occurring more slowly, the shift in pattern can be expected for the migration of minority groups in the future.

In addition to these explanations for nonmetropolitan growth, the recently improved terms of trade for agricultural production, with attendant high prices and profits, should bring higher wages and increases in farm employment if the changed market conditions persist. (Admittedly, the long-term substitution of nonhuman for human inputs can limit growth in agricultural employment, but at least some city-to-farm reverse migration now seems plausible.)

Some perspective on regional migration flows can be obtained from Table 3, which gives recent interstate migration flows (people moving from one state to another). Central cities in all regions had net outflows of migrants between March 1970 and March 1973, although the change was most pronounced in the northeast and north central regions and the net losses in the south and west were only limited. A similar pattern occurred for the remainder of the metropolitan areas; the northeast and north central had net outflows and the south and west net inflows of migrants. For nonmetropolitan areas, however, only the northeast had net outflows. The northeast had the lowest ratio of inmigrants to outmigrants in every locale, central cities, remainder of metropolitan areas, and nonmetropolitan areas. The highest ratio for both central cities and nonmetropolitan areas occurred in the west, though the ratio for the south was almost as large. For the remainder of SMSAs, the ratio for the south was well above that of the other regions, including the west. For regional aggregates, the order was south, west, north central, and northeast for both the ratio and the total net immigration. It is plausible that the same pattern, though less pronounced, holds for total population changes.

Some information is available on recent population changes for individual metropolitan areas (10). From April 1970 to July 1972, the population of all SMSAs combined grew 2.18 percent, whereas nonmetropolitan areas grew 2.27 percent. It is noteworthy that growth in the 15 largest SMSAs (populations over 2 million) averaged less than

1 percent, and five of the group registered small declines (New York City, Los Angeles, St. Louis, Pittsburgh, and Cleveland). In contrast, 52 of 235 smaller areas grew by more than 5 percent.

Individual area statistics were analyzed in detail by forming the ratio of 1972 to 1970 population for each SMSA and relating the ratio to population size and region. Initially, six population size classes were set up, and inspection of the data led to the classification of three fast-growing subregions:

1. Pacific Southwest desert and shore consisting of Arizona, Nevada, and California SMSAs below 2 million population and excluding the California central valley SMSAs, which typically had somewhat lower growth rates;
2. All Florida SMSAs except Titusville-Cocoa-Melbourne, which lost population because of cutbacks in the space program; and
3. Texas SMSAs ranging in 1970 from 140,000 to 2 million population.

There were 13 SMSAs in each grouping. Average population ratios for these classifications are given as Table 4. Aside from the high-growth subregions, it seems that growth declines as size increases, and there is the suggestion of such a pattern for the high-growth subregions as well, although it is less pronounced. The inverse relation between size and growth was confirmed by statistical test. Regression analysis was used to relate the growth ratio to population size and region; dummy variables were used for the major census regions and for the three fast-growing subregions. Before the subregions were introduced, both south and west were statistically significant. After the subregions were introduced, however, only the west retained significance. Thus, accounting for the high-growth subregions caused the south as a whole to drop out as a significant variable; i.e., high growth in the south seems specific to Florida and middle-sized Texas SMSAs. When brought into the equation, both the south and northeast had small positive effects, relative to the north central region as base. Most of the SMSAs in the south are in the small size classes, whereas the opposite holds for the northeast, where a greater proportion of SMSAs are in the larger size classes than holds nationally. Hence, some of the differential growth between regions appears to be attributable to size effect, since 1970 population size was statistically significant with negative coefficient.

The statistical results obtained are given in Table 5. The basic growth ratio of 1.02195 is adjusted by population size; thus, for a population of 0.5 million, we obtain 1.02195 - 0.5 (0.00349) = 1.02020, the estimated growth rate. This value applies for SMSAs outside the fast-growing regions. If we want the fitted ratio for Florida, we obtain 1.02020 + 0.05658 = 1.07678; the value for the Pacific Southwest is obtained by adding the coefficients for both that region and the west, i.e., 1.02020 + 0.01899 + 0.02973 = 1.06892.

The results can be summarized as follows:

1. With increasing size, there is an increasing drag on growth, and
2. Rapid growth tends to be localized in specific subregions.

Hypotheses explaining these results can be based on a number of presumptive causative factors by drawing on outside evidence. It seems plausible that one of the major causes is an equilibrating process involving a shift from more to less congested places.

Part of the population shift involves the migration of retired persons to pleasant places (the sunny coasts) or to places with a lower cost of living; because the cost of living is higher in the north and increases with size (11), people on fixed incomes have higher real incomes in the south and their real income increases the smaller the locale in which they live is. If we assume that similar migration patterns also hold for workers, real "net" wages are higher in areas with the highest rate of growth. It seems plausible that level of highway service is a factor in both the regional and the

Table 3. Migration flows of population, March 1970 to March 1973.

Locale and Region	Number of Migrants in Thousands: From Origin March 1970	To Destination March 1973	Net Flows	Ratio In/Out
Central cities				
Northeast	869	314	-555	0.361
North central	1,179	589	-590	0.500
South	1,324	1,202	-122	0.908
West	899	889	-10	0.989
	4,271	2,994	-1,277	0.701
Remainder of SMSAs				
Northeast	1,067	886	-181	0.830
North central	1,100	1,016	-84	0.923
South	993	1,856	863	1.869
West	924	1,240	316	1.342
	4,084	4,998	914	1.224
Outside SMSAs				
Northeast	507	470	-37	0.927
North central	853	1,007	154	1.181
South	1,468	1,559	91	1.062
West	702	857	155	1.221
	3,530	3,893	363	1.103
Regional totals				
Northeast	2,443	1,670	-773	0.684
North central	3,132	2,612	-520	0.834
South	3,785	4,617	832	1.220
West	2,525	2,986	461	1.183
	11,885	11,885	0	1.000

Table 4. SMSA population growth by size.

Population Class[a] (in thousands)	Average Ratio[b] of 1972 to 1970 Population: SMSAs in High-Growth Subregions	Other SMSAs	Distribution of SMSAs: In High-Growth Subregions	Other
<150	1.0790	1.0228	9	59
150 to 250	1.0668	1.0224	8	39
250 to 500	1.0641	1.0197	11	52
500 to 1,000	1.0664	1.0190	4	34
1,000 to 2,000	1.0615	1.0158	7	12
>2,000	–	1.0073	0	15

[a] 1970 population.
[b] Essentially the same as the weighted average ratio.

Table 5. Regression equation results for ratio of 1972 to 1970 population as dependent variable.

Independent Variable	Coefficient	t Ratio
Constant	1.02195	506.965
Population in 1970		
(in millions)	-0.00349	2.367
West	0.01899	3.664
Pacific Southwest	0.02973	3.540
Florida	0.05658	7.974
Texas, middle-size	0.01899	5.267

Note: $\bar{R}^2 = 0.3397$.

Table 6. Average growth of all places with 1960 population of 10,000 or more by distance to nearest SMSA and accessibility to Interstate highways.

Distance From SMSA (miles)	Accessibility	Places: Number	Percent
<50	High	585	27.6
	Average	399	16.7
	Low	41	15.5
	None	24	14.6
50 to 100	High	36	15.0
	Average	103	13.8
	Low	52	5.6
	None	24	2.2
100 to 150	High	15	15.4
	Average	114	15.1
	Low	98	10.0
	None	111	6.7
>150	High	3	14.7
	Average	55	17.2
	Low	22	4.2
	None	64	7.1

urban growth patterns. The larger the urban area is, the greater the cost of operating a car (e.g., parking costs, insurance, and accident costs not covered by insurance), the longer the journey to work, and the greater the traffic congestion and pollution. Such costs may help limit the growth of large areas. Further, the newer urban areas of the south and west typically have much better highway networks than those of the northeast and north central regions.

The thesis that level of highway service is an important factor in urban growth is supported by data given in Table 6, which relates 1960-1970 growth for places of at least 10,000 population to access to Interstate highways and proximity to an SMSA. Caution must be exercised in interpreting the future, however, because it is possible that some of the causation runs the other way, i.e., that fast growth generates highway construction, or that both fast growth and highway construction are caused by other factors. For example, areas with comparative economic advantage may have that advantage because they are newer, and, because they are newer, their land use pattern was influenced by the automobile and, hence, is of lower density and has lower costs for highway construction. Nevertheless, it is plausible that at least some of the causal relation flows from highway access to growth. With increased access, a number of costs must decline, which increases real income.

Intraurban Patterns

Although evidence shows a continued shift of population from central cities to suburbs, other evidence suggests some current diminution of suburban sprawl and a likely future buildup of population densities in urban areas. Increasing densities can be tied to a corresponding movement toward saturation of automobile ownership (as an asymptotic limit). The density buildup can be expected first in the west, given present high rates of automobile ownership in that region, whereas sprawl should continue for some time in areas of relatively low automobile ownership rates, the northeast, in particular. Evidence on automobile ownership rates is more suggestive than definitive, but the items of evidence are consistent with each other and with economic theory applied to urban land use.

That theory is concerned with the trade-off of space for access (or of rent for travel costs), which accounts for the distribution of urban population per unit of land area, which is approximated by

$$D = Ae^{-bK} \qquad (3)$$

where

D = population density,
K = distance from the center in any direction ($K \geq 0$), and
A and b = parameters.

With $K = 0$, $D = A$, or density at the center, b is termed the density gradient, which measures the relative rate of decline from the center (14, 15). Shifts in the density relation can be related to (a) population growth, (b) crowding effects, including congestion, air pollution, and noise, and (c) transportation improvements. As population increases in an area, other things being equal, we can expect increased demand for land at all points, a general bidding up of land values, and a corresponding increase in population density. If there were no crowding effects, we could hypothesize a constant percentage increase everywhere; however, crowding effects are likely to be strongest the higher the density is, tending to inhibit growth near the center and to increase it at the periphery of the urban area. Finally, as transportation improvements make outer areas more accessible to the center, we can expect a shift of population outward and corresponding declines in the values of both A and b in Eq. 3. Over time, higher per capita incomes reinforce both the crowding and transportation improvement effects through increased automobile ownership and shifts to single-family housing.

Figure 2 shows the argument in diagram form (15, p. 95). The density-distance relation is plotted in terms of the log of density, which yields a linear relation of the form

$$\log D = \log A - bK \tag{4}$$

Line 1 is the initial pattern, and line 2 represents the effect of a once-and-for-all transportation improvement, which implies lowered density at the center and higher density at the periphery. The intercept, log A, declines, as does the absolute value of b; because the slope is negative, its upper bound is zero. Line 3 exhibits the effect of population growth and assumes crowding effects; if the increase were the same percentage at every distance, in the logs this would be the equivalent of adding a constant to line 2. However, with crowding effects, which inhibit growth near the center, the increase is less than proportionate near the center and greater than proportionate at the periphery. In reality, of course, transportation improvement and population growth occur in a continuous process over time. But there is some basis for hypothesizing that the shift from 1 to 2 was predominant in the recent past, whereas that from 2 to 3 is likely to be strongest in the future.

Some evidence is available to support these conclusions. Muth estimated the density function for 46 U.S. cities for 1950 (15, p. 142). By regressing the logs of Muth's parameter estimates on log of urbanized area population and regional dummy variables, we obtain results supporting Figure 2. Putting the equations in antilog form yields the following estimates:

$$A = 6.03\ (1.71)^{NE}\ (0.73)^{W}\ P^{0.208} \qquad R^2 = 0.26 \tag{5}$$

$$b = 4.54\ (1.49)^{NE}\ (0.90)^{W}\ P^{-0.424} \qquad R^2 = 0.34 \tag{6}$$

where P is urbanized area population and NE and W are regional dummy variables that take on values of 0 for observations outside the given region and 1 for observations within the region. (The south and north central regions are excluded.) In the latter regions, A equal 6.03 times the population effect, $P^{0.208}$. In the northeast, A equals (6.03) (1.71) or 10.31 times the population effect; and in the west, A equals (6.03) (0.73) or 4.40 times the population effect, reflecting regional variations in urban density pattern, which fit with the shift from line 1 to line 2 in Figure 2. With population increases, there is some increase in A as well as a decrease in the absolute value of b, which shows that density increases at the center as well as at the periphery, given population growth. However, the population exponent in Eq. 5 has a low value, and the hypothesis that it equals one is rejected, showing that population increases are more than proportionate at the periphery and less than proportionate near the center.

Barr (16) obtained individual city estimates of A and b for 1960 by using essentially the same sample of census tracts that Muth had used for 1950. He obtained estimates for only 30 cities because of massive redefinition of census tracts in the remaining cases. Between 1950 and 1960 both A and b decreased substantially, presumably reflecting the growth in intraurban highways and attendant suburbanization. Comparing Barr's estimates to Muth's shows that the 1960 value of A declined to 0.65 and the value of b declined to 0.63 of the corresponding 1950 value, on the average. These changes correspond to the shift from line 1 to line 2 in Figure 2. Regression results using the Barr estimates as data parallel those for the 1950 cases:

$$A = 2.89\ (1.92)^{NE}\ (0.63)^{W}\ P^{0.236} \qquad R^2 = 0.21 \tag{7}$$

$$b = 11.80\ (1.41)^{NE}\ (0.69)^{W}\ P^{-0.616} \qquad R^2 = 0.34 \tag{8}$$

Figure 2. Relation of urban population density to distance from urban center.

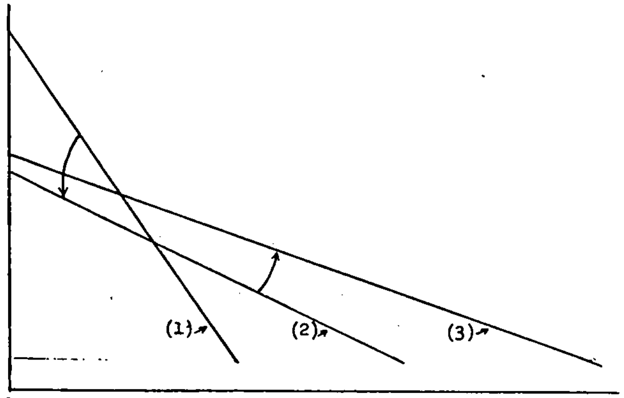

Table 7. Density equation results.

Estimate	Year	Baltimore	Kansas City	Denver	Los Angeles	Riverside	San Bernardino
Log A (intercept)	1950	4.226	—[a]	3.599	3.517	—[a]	0.961
	1960	3.556	1.737	2.220	3.127	1.136	1.211
	1970	3.102	1.866	2.192	3.033	1.300	1.198
b (coefficient)	1950	0.649	—[a]	0.706	0.246	—[a]	0.303
	1960	0.387	0.174	0.148	0.169	0.230	0.228
	1970	0.258	0.155	0.143	0.148	0.162	0.191
Change in log A	1950 to 1960	-0.670	—[a]	-1.379	-0.390	—[a]	0.250
	1960 to 1970	-0.454	0.130	-0.028	-0.094	0.164	-0.013
Change in b	1950 to 1960	-0.262	—[a]	-0.558	-0.077	—[a]	-0.075
	1960 to 1970	-0.129	-0.019	-0.005	-0.021	-0.068	-0.037
$\bar{R}^2$		0.681	0.436	0.389	0.645	0.671	0.535
N		112	76	81	219	76	90

[a]Not available.

Table 8. Percentage of automobile-owning households by income and residence.

		Annual Family Income					
No. of Cars	Place of Residence	<$5,000	$5,000-7,499	$7,500-9,999	$10,000-14,999	>$15,000	All Income Groups
1 or more	Central cities of 12 largest SMSAs	22	45	83	83	78	58
	Central cities of other SMSAs	43	78	85	95	90	70
	Suburban areas of 12 largest SMSAs	53	93	93	98	95	89
	Suburban areas of other SMSAs	63	96	96	98	99	90
	Adjacent areas of SMSA	68	95	98	99	98	86
	Outlying areas of SMSA	51	92	97	99	97	76
	All places	52	85	93	96	95	79
2 or more	Central cities of 12 largest SMSAs	1	4	7	22	22	10
	Central cities of other SMSAs	3	17	25	47	51	21
	Suburban areas of 12 largest SMSAs	5	27	29	38	66	37
	Suburban areas of other SMSAs	12	11	30	55	74	36
	Adjacent areas of SMSA	8	24	33	43	67	26
	Outlying areas of SMSA	5	24	39	40	59	21
	All places	5	19	28	41	62	26

The hypothesis that the exponent of P equals 1 in Eq. 7 is again rejected.

Table 7 gives fitted density equation results for six SMSAs in 1950, 1960, and 1970 (17). In some cases, residential density is low near the city center because the land use is other than residential. Therefore, observations of less than 1 mile were omitted for Baltimore and Denver and less than 2 miles for Kansas City and Los Angeles. Coefficient estimates were appreciably affected only for Kansas City, but $\bar{R}^2$ improved in all other cases.

In general, the decline in log A and in absolute value of b is much less pronounced between 1960 and 1970 than it was between 1950 and 1960. In the later period, only Baltimore showed a change consistent with a strong shift of the line 1 to line 2 variety. In all of the other areas, that shift seems much less pronounced; log A is relatively stable in three of the areas and even shows a slight increase in the other two, whereas the value of b shows only a small decline. Thus, some support emerges for the hypothesis that the impact of road-building and automobile ownership on density is still considerable in the east, but is greatly attenuated in the west. It seems worth noting that Baltimore's density relation for 1970 roughly corresponds to that of Los Angeles about 15 years earlier. (In 1970, Baltimore's intercept is roughly that of Los Angeles in 1960, and its slope corresponds to that of Los Angeles in 1950.)

TRENDS IN AUTOMOBILE OWNERSHIP

The regional pattern of automobile ownership (18) parallels the urban density pattern by region, as demonstrated by the following data on percentage of households owning cars in 1971:

Region	At Least One Car	Two Cars	Three or More Cars
Northeast	73.1	21.3	4.5
North central	83.6	26.3	5.7
South	79.2	24.9	4.1
West	85.9	28.1	5.2
U.S.	80.0	25.0	4.8

Besides density, income is a major factor explaining automobile ownership. The joint effects of the two factors (19) are indicated by the data given in Table 8.

Maximum or "ultimate" car ownership levels can be estimated as follows. Available evidence indicates that the ultimate percentage of Americans owning one or more cars is 97 and the percentage owning three or more cars is 15. Given the data of Table 8, it is possible to estimate "ultimate" percentages for two-car households under some fairly reasonable assumptions. Assume that the percentage of car ownership for the highest income class is very close to the ultimate percentage for each locale, and project an ultimate population distribution by locale. (An income of $15,000 in 1968 corresponds to $19,200 at 1973 prices.) This procedure provides the data given in Table 9.

With the 1970 population distribution, ultimate U.S. ownership of two or more cars is 60.8 percent of all households; under the ultimate distribution that figure rises slightly to 62.7 percent. We can now obtain total cars per household for 1971 and for the ultimate period by noting that each category involves a one-car increment (assuming three cars and over is very close to 3.0). We find:

Cars	1971	Ultimate
First	0.80	0.97
Second	0.30	0.63
Third	0.05	0.15
	1.15	1.75

Table 9. Estimation of ultimate automobile ownership levels.

Area	Location	Maximum Percentage With 2 or More Cars	1970 Population Distribution	Ultimate Population Distribution
Central cities	12 largest SMSAs	25	11.1	8
	Other SMSAs	55	20.3	17
Suburbs	12 largest SMSAs	67	14.1	13
	Other SMSAs	75	23.5	27
	Adjacent areas	68	15.0	17
	Outlying areas	60	16.0	18

Table 10. Percentage of households owning automobiles by locale.

Car Ownership	Residence	1964	1965	1966	1967	1968	1969	1970	1971
1 or more	Central cities								
	12 largest SMSAs	54	57	56	54	58	55	62	61
	Other SMSAs	80	77	77	73	70	67	66	78
	Suburban areas								
	12 largest SMSAs	83	90	86	88	89	91	91	91
	Other SMSAs	88	88	92	87	90	88	89	90
	Adjacent areas to SMSA	84	83	85	86	86	86	86	89
	Outlying areas to SMSA	75	76	75	76	76	77	83	82
	All areas	78	79	79	78	79	79	82	83
2 or more	Central cities								
	12 largest SMSAs	14	10	11	9	10	11	18	15
	Other SMSAs	24	22	24	22	21	22	27	30
	Suburban areas								
	12 largest SMSAs	25	39	32	36	37	39	46	41
	Other SMSAs	33	33	37	34	36	39	35	34
	Adjacent areas to SMSA	24	26	28	27	26	29	29	29
	Outlying areas to SMSA	15	18	18	20	21	20	20	18
	All areas	22	24	25	25	26	27	28	28

Table 11. Percentage of households owning automobiles by income class.

Car Ownership	Income (dollars)	1964	1965	1966	1967	1968	1969	1970	1971
1 or more	<1,000	32	27	24	25	27	32	25	13
	1,000-2,000	33	43	31	38	38	39	41	34
	2,000-3,000	70	56	54	53	48	46	50	52
	3,000-4,000	72	68	67	63	63	54	60	61
	4,000-5,000	72	76	76	76	73	68	70	71
	5,000-6,000	86	82	84	82	81	78	75	83
	6,000-7,500	87	88	89	86	89	88	86	89
	7,500-10,000	94	94	93	93	93	93	92	89
	10,000-15,000	98	97	96	95	96	95	96	95
	>15,000	93	94	95	93	95	97	96	97
2 or more	<1,000	3	2	3	6	0[a]	1	3	0[a]
	1,000-2,000	2	2	3	2	2	4	1	0[a]
	2,000-3,000	8	6	3	5	1	1	7	0[a]
	3,000-4,000	11	12	6	10	10	8	6	9
	4,000-5,000	12	12	11	14	13	7	9	10
	5,000-6,000	19	17	16	15	17	15	9	12
	6,000-7,500	19	21	21	19	21	18	15	19
	7,500-10,000	34	32	30	29	28	31	26	26
	10,000-15,000	46	47	46	45	41	44	41	40
	>15,000	57	57	60	62	62	61	60	54

[a] Less than 0.5 percent.

The second-car increment in 1971 is obtained by adding the fraction for those with exactly two cars (0.25) to the fraction for three or more (0.05), thus accounting for the latter group's second car. However, the proper second-car fraction in the ultimate case equals that for those owning two or more cars.

It follows that the ultimate ownership rate is about 52 percent above that for 1971 (1.75/1.15 = 1.52). If we accept the census bureau's F series projection of a maximum population of 270 million, the ultimate growth in population is about 28 percent of the present level. The population and car ownership projections combined yield a projected ultimate number of cars equal to around twice the present level (1.52 × 1.28 = 1.95). The E series projection of the ZPG level is 320 million or 1.52 times present population. Under this projection, ultimate car ownership is about 2.3 times present levels (1.52 × 1.52 = 2.31). Inasmuch as these are estimates of ultimate levels, intuitively they do not seem very large. Some may well be encouraged by these magnitudes.

Time series data are not readily available on car ownership by both income and locale; most series relate ownership percentage to only one of these factors, so that changes in the other factor are not controlled. Thus, an apparent trend in one set of percentages may well reflect changes in the uncontrolled factor. Table 10 gives car ownership percentages by locale, whereas Table 11 gives those percentages by income. The percentages are based on surveys with a sample size of 2,500 (the 1971 survey had only 1,300 observations). Hence, sampling variability can cause distortions also. In Table 10, some upward trend is manifested in all locales, though the change is small for suburban areas since 1965 because of their high initial percentages. It is likely that much of the upward trend can be explained by increases in real income.

Data given in Table 11 appear remarkable for an apparent absence of trend, though increased suburbanization would cause some upward shift in car ownership. The absence of trend is more apparent than real because income data are in current dollars, and (as we are all aware) there has been marked inflation in recent years. The data given in Table 11 seemed worth detailed analysis for the information they might yield on suburbanization, assuming that most of the discerned shifts in relationships could be attributed to that cause. Data of the same form were available for the years 1950 through 1965 from a study by Lansing and Hendricks (20), and the two series were merged so the period 1950 through 1971 was covered. The income measures for the earlier period were in constant dollars on a 1957-1959 base, in contrast to the current dollar measures of the later series. We used consumer price level deflators to convert all data to 1973 dollars. Car ownership was related to income for each subsample separately, and patterns of year effects were determined. Then the subsamples were pooled, and separate regression relations were estimated for percentages owning one car and two or more cars, based on the patterns of year effects. For percentage owning one or more cars, observations were omitted for incomes above \$12,500 (1973 prices) because this seemed to be the upper bound for the ownership-income relation. Both intercept and slope shifts were investigated, but the final form of equation accepted was based on statistical significance (22). For percentage owning one or more cars, the equation had the following form:

$$(\% \ 1 + \text{car}) = (a + b_1 B_1) + (c\$ + dT\$)$$

where

$\$$ = income in thousands of dollars,
T = year minus 1950,
b_1 = the coefficient of a dummy variable,
B_1 = representing a set of years in a grouping, and
T$\$$ = the product of T and $\$$.

The equation form specifies both intercept and slope shifts over time; intercept shift is accounted for by b_i and slope shift by dT. The numerical results obtained are given in Table 12.

Significant intercept shifts occurred only in the earliest years of the series (covering 2-year periods from 1950 through 1955), but a significant slope shift occurred over the entire period, 1950-1971. A linear equation for a given year can be obtained directly from Table 12. Thus, for 1950, we have (% 1 + car) = 27.36 + 5.14 \$; and for 1970, (% 1 + car) = 32.80 + 6.16 \$. The fitted equations for 1950, 1955, and 1970 are shown in Figure 3. It seems that the upward shift in ownership has decelerated since the early 1950s, which is hardly surprising, given the high level attained some time ago.

For percentage owning two or more cars, the equation has this form:

$$(\% \text{ 2 car} +) = (a) + (b_i B_i \$ + c\$ + dT\$)$$

In this equation, the intercept is stable over time and there are two kinds of slope shifters: dT shifts the slope in a regular fashion, whereas $b_i B_i$ generates an irregular shift specific to a particular grouping of years. Numerical results are given in Table 13.

Fitted equations for specific years can again be obtained by appropriate multiplications and additions. Thus, for 1950, the equation is (% 2 car +) = 2.697 + 1.003 \$, and, for 1970, the equation is (% 2 car +) = 2.697 + 2.904 \$. [In 1970, the slope is equal to 1.003 + 0.0294 T + 1.313 (1) or 1.003 + (20)(0.0294) + 1.313.] Fitted equations for some specific years are shown as Figure 4. Data given in Table 13 and Figure 4 seem to indicate an initial accelerating upward shift in the relationship, followed by a decelerating shift in recent years. If we divide the increment in the slope shift (B_i\$) for each period by the number of years covered and add the common shift (T\$), we find the following estimated annual shifts from Table 4:

Year	Shift
1950-52	0.0294
1953-54	0.0925
1955-58	0.0897
1959-62	0.0840
1963-66	0.1401
1967-68	0.1294
1969-71	0.0577

There is a peaking in the 1963-66 period and a substantial falling off in the most recent period. If we interpret the shift as indicative of the suburbanization process (or sprawl), the slowdown in the shift may be taken as additional evidence that sprawl may be approaching a limit and that future urban densities are likely to increase.

It may be noted that the data given in Tables 4 and 5 might be extended to future years; then, given forcasts of the income distributions for those years, forecasts of car ownership for specific future years could be derived. Such forecasts would suggest how fast car ownership is approaching the "ultimate" levels presented earlier.

Those forecasts might be affected somewhat by increased energy prices, and by air pollution and noise regulation. Higher gasoline prices will make long automobile trips more expensive and location at the urban periphery less attractive. Cost per mile driven and the purchase price of automobiles have also increased because of air pollution control devices. All of those cost increases may slow down automobile purchases, although the major effect might well be a shift to smaller cars. Air pollution and noise abatement should lead to some countering of the flattening effect on intraurban population distribution caused by such externalities. Insofar as such environmental changes make large cities more attractive than small ones, there may also be some reversal of the relative shift of population from large places. All of these trends will reinforce the shift toward higher population densities.

CONCLUSION

Some inferences can be drawn, and a number of hypotheses formulated, on the basis of the trends examined in this paper.

The problems of growth at the national level and in terms of the burgeoning of "too" large urban areas appear to have been grossly overstated in recent years. At the national level, in fact, it is likely that lack of growth will eventually be seen as a problem, as will attendant labor "shortages" (23). At the urban area level, the inverse relation between growth rate and size and the little or no growth of the largest areas agree with the hypothesis that there are eventual diseconomies of scale, including increased congestion and pollution effects. In response, people can and do move to more pleasant and generally smaller places.

The slowdown in total growth and in growth of large areas and the shift of population to less congested places should imply a considerable slowdown in high construction needs. The U.S. Department of Transportation has estimated a need in 1990 for approximately 18,000 miles of additional freeways and expressways within urbanized areas, compared to about 8,000 miles in 1968 (24). That estimate may be too high if earlier growth patterns were used in its development.

The discerned shifts in population can be viewed as part of an equilibrating process, improving congestion problems in dense areas and making them somewhat worse in places that are currently less dense and les congested. This pattern is likely to be intensified if we are, in fact, moving toward saturation of automobile ownership. Available evidence lends support to the hypotheses that suburban sprawl and, concomitantly, increases in automobile ownership are likely to continue at near their former pace only in the high-density areas of the east, while the rest of the country, led by the west, enters an era of building up of densities at distances from the urban center and much slower growth in automobile ownership. If developed far enough, the pattern of increasing urban densities may make public transit operations more viable in a number of areas. They may not become profitable, but losses ought to be reduced. Given a commitment to extensive investment in public transit facilities, in any event, some density increases can thus be viewed in optimistic fashion.

It might be added that public transit investment will probably be an additional causal factor yielding higher urban densities. In general, of course, causation runs both ways for transportation and land use. Higher gasoline prices and air pollution regulations affecting the cost of automobile operation should also inhibit suburban sprawl. Parenthetically, air pollution regulation initially involved some planned use of pricing to ration automobile use and, hence, reduce pollution, but that development now seems less likely.

The patterns of population redistribution and the possible coming saturation of automobile ownership can be viewed as benign, even hopeful, developments that will tend to reduce traffic congestion and perhaps to reduce needed highway investment and to make public transit a more economic investment.

Although market-like processes can be discerned in trends, that does not vitiate the need for planning, benefit-cost analyses, and policy devices, including pricing. The use of such devices might speed up or even reverse the trends.

Nevertheless, present trends seem to mean a considerable reduction of the pressure for solutions to transportation problems. It is hoped that the time gained will be used constructively.

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Table 12. Regression equation results for percentage owning one or more cars.

Variable	Coefficient	t-Ratio
Constant	32.8016	28.413
Intercept shifting dummy, B_i		
1950-1951	-5.4439	2.388
1952-1953	-3.6551	1.788
1954-1955	-1.8163	0.900[a]
$(thousands of dollars)	5.1376	24.772
T$	0.0510	3.049

Note: $\bar{R}^2 = 0.897$, number of observations = 186.
[a]Included because omission caused other dummies to lose significance.

Table 13. Regression equation results for percentage owning two or more cars.

Variable	Coefficient	t-Ratio
Constant	-2.6966	9.936
$	1.0030	25.437
T$	0.0294	2.322
Slope shifting dummies, ($B_i$$)		
1950-1952	0[a]	—[b]
1953-1954	0.1262	2.144
1955-1958	0.3672	4.538
1959-1962	0.5854	4.601
1963-1966	1.0282	5.947
1967-1968	1.2282	5.696
1969-1971	1.3130	5.356

Note: $\bar{R}^2 = 0.972$, N = 278.
[a]Set equal to zero because one dummy is omitted to avoid colinearity.
[b]Not applicable.

Figure 3. Estimated percentage of families owning at least one car as a function of income.

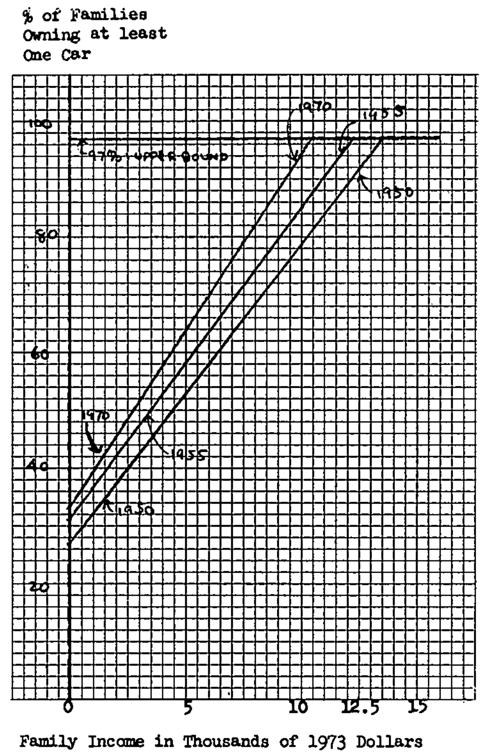
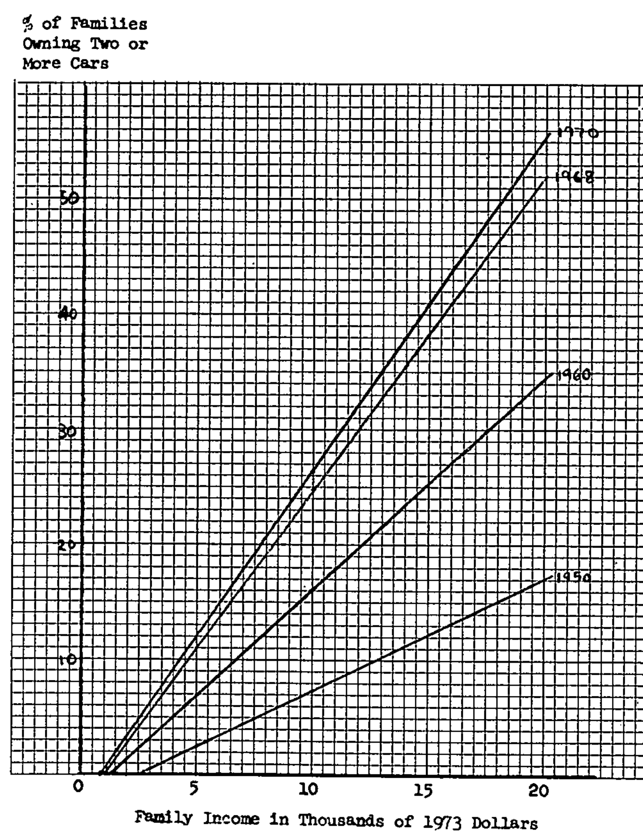


Figure 4. Estimated percentage of families owning two or more cars as a function of income.



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