The Effect of Modern Highways on Urban Manufacturing Growth

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This study attempts to determine whether cities with superior intercity highway connections enjoy more rapid manufacturing growth, i.e., whether relatively fast, low-cost motor transportation attracts industry. Manufacturing growth rates are compared for two groups of cities, an experimental group located on Interstate System freeways and a control group located elsewhere. The two groups are comparable in all major respects—population, location, air service, economic activity, etc.—except highways; comparability rests on the matched pairs procedure (106 city pairs). A city's growth is its per capita manufacturing employment increase between 1958 and 1963. Differences between group means are tested for significance for all pairs combined and many breakdowns. To clarify the relationship between growth and distance from freeway, correlations for hundreds of curvilinear relationships are compared. Nationwide, there was no significant difference in freeway and nonfreeway performance. But in regions with dense population and uneven terrain—the Northeast, Southeast, East Midwest, and Far West—freeway cities grew much faster. In these regions the freeway advantage was largely confined to cities either above 16,000 in population or served by airline, for which cities significance levels ranged as high as 0.01. The growth-distance relationship is best described by a probability curve peaking at zero miles and having a standard deviation of 5 miles: freeways have little effect on cities more than 10 miles away.

•ONE of the major knowledge gaps in the field of domestic economic development concerns the effect of modern highways on urban manufacturing growth. The present study attempts to determine whether superior highway facilities stimulate industry. The principal finding is that, under some conditions, cities on modern highways grow significantly faster.

SUMMARY

This study was designed to develop knowledge regarding (a) whether cities with good transport facilities have more capacity for growth than other cities and (b) whether transport investment is itself an effective means of promoting economic growth. Toward these ends it compares manufacturing growth rates for two groups of cities, an experimental group and a control group. The first group has superior highways (the Interstate System); the other does not. Cities within 8 miles of Interstate System exits—hereafter called freeway cities—were placed in the experimental group. Cities

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more than 15 miles from Interstate freeways—hereafter called nonfreeway cities—went into the control group. All cities above 5,000 population from the 48 contiguous states were first screened to eliminate suburbs, satellites, and other cities whose proximity to nearby ones might influence their own industrial "pull." For the surviving cities information was recorded on geographic location, population, air service, economic activity, and other factors likely to affect growth. Cities were then matched by pairs, freeway cities with nonfreeway. Paired cities had to be reasonably close to each other, have approximately the same population, have the same type of air service, etc. This operation netted 106 city pairs, or 212 cities. These represented 40 states, and all but a few were between 10,000 and 50,000 in population. Growth data were recorded from the 1958 and 1963 Censuses of Manufactures; the experimental period was 1958-63. Growth was measured by computing freeway and nonfreeway group means for the per capita manufacturing employment changes of individual cities. Experimental and control group comparisons were made for all cities combined and numerous breakdowns.

The study results suggest that superior highway facilities can be an important stimulus to manufacturing growth but only in certain regions and mainly under certain conditions. In the findings below, growth is expressed as new jobs per thousand capita.

- Nationwide, combining all 106 pairs, freeway cities grew slightly faster (19 jobs per thousand capita vs 16) but the difference was not statistically significant.

- In the Southeast, East Midwest, and Pacific Northwest (three fast growing regions with dense population and uneven terrain); the freeway cities outgrew the nonfreeway ones by a 43 to 23 margin, significant at the 0.04 level.

- In these three regions combined with the slow growing Northeast, pairs above 16,000 gave the freeway side a 27 to 4 advantage, significant at the 0.03 level.

- In the same four regions freeway cities had a 27 to 2 advantage among pairs served by air; significance: 0.04.

- Combining cities above 16,000 with the remaining airline cities in the four regions produces a freeway advantage of 27 to 5, significant at the 0.02 level. In the three fast growing regions (Northeast omitted) the margin is 36 to 8, significant at the 0.01 level.

- Nonfreeway cities within 16 to 25 miles of the nearest freeway exit did not grow faster relative to their mates than more distant nonfreeway cities. The growth-distance relationship is best described by a probability curve (bell shaped) with a standard deviation of about 5 miles and a peak at zero miles.

- Although growth is correlated with industry among the crucial pairs, partial correlations between growth and distance to freeway, with industry and other variables controlled, are higher than the original correlations.

- Whereas the two groups were equal in manufacturing, correlations between industry variables and growth reached +0.93 for freeway cities but only +0.33 for nonfreeway cities, suggesting that freeways affect growth indirectly, as a catalyst for the industry stimulus, as well as directly.

These findings indicate that intercity freeways bolster manufacturing growth in regions where travel on regular highways is especially impeded by heavy traffic, frequent towns, and numerous hills and curves; that is, in regions with dense population and topographic irregularities. The area of significance includes the Pacific Northwest (no data for California) and everything east of the Mississippi Valley states (east of Illinois and Mississippi); the Great Plains mark the approximate limits of the eastern sphere of influence. In the indicated regions, transport sensitive industry is attracted mostly to cities above 16,000 in population or with air service; hence freeways have the most influence in these categories.

PURPOSE OF STUDY

Domestic economic development is a subject of concern not only to the Federal Government but to states and localities as well. Federal programs seek to aid small areas and large regions with high unemployment rates and low income levels; state and local programs are more broadly concerned with securing faster rates of economic growth. Frequently, developmental investments are used to attract industry. Sometimes, as in the case of the billion dollar Appalachian road program, these investments involve transportation. To spend the investment dollar wisely, we need to know which communities have the greatest capacity for growth. Is the, say, industrial park more likely to pay off in a city with good transportation? We also need to know whether transport facilities themselves, as a particular form of developmental investment, can effectively stimulate economic growth. The central role of highways in transportation and of industry in economic development makes it important to learn whether highways contribute to urban manufacturing growth.

To date, this relationship has received very little study. Industrial location research has shown that transportation in the abstract is a major determinant of plant location. What we do not know, however, is whether good highways, as a specific type of transportation, significantly influence manufacturing growth. True, there has been considerable study of the relationship between new roads and commercial establishments—motels, gas stations, restaurants, stores, etc. Some studies have also touched upon manufacturing, though primarily from the standpoint of where new plants locate within a municipal area (beside the new highway or two miles away?). The developmental economist, however, is more interested in another question, namely: do communities with superior highway connections enjoy faster manufacturing growth than other communities?

In theory, better highways might well influence manufacturing growth. Many new plants are branch plants or otherwise produce for regional distribution. They are located within certain regions for competitive reasons—primarily to minimize transport costs and shipping delays entailed in serving regional markets. Assuming that good roads reduce the time and expense of shipping goods to market, and to a lesser extent bring lower freight costs on supplies and raw materials, the roads could prove to be magnets for industry.

With these considerations in mind, the present study was designed to test the following hypotheses:

1. Freeway cities in general have higher manufacturing employment growth rates.
2. Freeway cities grow faster only, or increasingly, in regions where dense population and hilly terrain produce relatively large disparities in traffic speeds between freeways and regular highways.
3. Freeways stimulate urban growth but only/mainly in certain population ranges.
4. Freeways stimulate growth only/mainly where complemented by airline service—for executive transportation.
5. Freeways stimulate growth only/mainly in cities with poor rail service, where highway transport can serve as an offset.
6. Freeways stimulate growth only/mainly where water carrier service is present or absent.
7. There is a curvilinear relationship between growth and distance to the nearest freeway.
8. Freeways enhance any favorable relationship between prior industry and manufacturing growth rate.

METHODOLOGY

The study methodology is based on a well-known procedure for determining the effect of a specific factor or stimulus on mass performance. Two groups are compared, an experimental group and a control group. The groups are matched by pairs with respect to various factors which might influence performance. One group, however, carries the experimental factor (say, a drug in medical research) while the other does not (or gets the placebo). In this manner variables other than the one being tested are isolated or "controlled." At the same time, one tries to make both groups large enough to at least partially compensate for the random influence of hidden variables which cannot be specifically controlled. Properly applied, the procedure gives reasonable assurance that the groups as a whole are comparable, even though it is rarely possible to achieve more than a rough sameness between the two members of a pair.

In establishing experimental and control groups for the present study seven steps were taken: (a) establishing a criterion for identifying superior highway facilities, (b) screening out those cities whose growth might be affected by nearby cities, (c) recording descriptive information for use in matching experimental and control cities with similar features, (d) selecting preliminary pairs, (e) balancing the two groups of cities, (f) determining city growth rates, and (g) statistical analysis.

The Experimental Criterion

The criterion problem was readily solved. The 41,000-mile Interstate Highway System is a network of divided, limited-access freeways which are markedly superior to alternative routes in most situations. Its quality is consistent from place to place and over long distances. Interstate System cities can objectively be said to enjoy superior highway facilities. Hence the system, augmented by a few connecting freeways, becomes the criterion.

It might be objected that the system will not be completed until the mid-1970's. However, a new plant is a long-term investment and is likely to reflect long-range locational considerations. It is presumably not the Interstate segments completed during the study period which count but the entire network which will be operational for the bulk of the life of a new plant. (For this reason, freeway cities were selected without regard for whether portions of the System immediately adjacent to them had been completed.) Admittedly, there was originally some doubt as to whether the study period (1958-63) might not be too early to mirror industry's reaction, but the study findings adequately dispel this doubt.

Another problem was how close to or far from the nearest Interstate System access point should a city be to be classified as freeway or nonfreeway? A tabulation of distance-to-freeway for 550 cities located within 10 miles of System exits showed a natural breaking point of 5 to 7 miles: 501 of the 550 cities were within 5 miles and 530 within 7 miles. Seven miles became the cutoff distance (8 in one case), with all but 8 freeway cities actually used being within 5 miles. To insure adequate differentiation of nonfreeway cities, a gap of about 10 miles between the freeway maximum and nonfreeway minimum was employed. Nonfreeway cities were required to be at least 16 miles (one city) from the nearest Interstate System exit, and the median distance for nonfreeway cities used in the study was 40 miles.

Proximity Screening

Other research has shown that principal cities and their larger satellites are declining in their proportionate share of manufacturing employment while suburbs are gaining. And, going beyond principal cities, one can hypothesize that two nearby cities will act as a unit to some degree, attracting more industry in combination than they could in isolation. City A's influence on B can be expected to increase with A's size and decrease as the intercity distance goes up. To control the influence of proximity, therefore, a procedure for screening cities on the basis of the population and distance away of nearby cities was necessary.

As an arbitrary start, a decision was made to eliminate any city within 12 miles (10 plus 2 for good measure) of another city of 10,000 in population. Higher on the population scale, two other benchmarks were obtained by observing the natural scatter of communities around Boston and Chicago. For Boston (700,000) this was judged to extend about 35 miles and for Chicago (3,600,000) about 55 miles. The next step was to fit a curve to the three population-distance benchmarks. The curve, $D = \sqrt[3.75]{P}$

(distance equals the 3.75th root of population), fits very well. It demands 14 road miles of separation from another city of 20,000 population, 21 miles from a city of 100,000, 36 miles from a city of 700,000 (Boston), and 55 miles from a city of 3,600,000 (Chicago). This formula easily eliminates all cities classified as suburbs or satellites in the Rand McNally City Rating Guide as well as numerous others.

Descriptive Information

For all cities surviving proximity screening, descriptive information was recorded for use in (a) pairing freeway with nonfreeway cities and (b) preparing statistical breakdowns. This information covered geographic location, population, road mileage to nearest Interstate exit, rail service, air service and airports, water carrier service, port facilities, governmental institutions, educational institutions, manufacturing value added (1958), and several economic and special activity ratings.

The necessary data came from many sources. Cities were located by road map coordinates to facilitate subsequent measurement of intercity separation among paired cities. Population figures came from the 1960 Census. Distance to freeway was measured from road maps. Rail service, for which only a crude measure could be developed, was recorded from a railroad atlas in terms of the number of directions in which rail lines ran from a city. Airline route maps and the FAA National Airport Plan provided information on airline service, while the Plan and road maps revealed the location of airports not served by airline. Water carrier service was recorded from a map of inland and coastal waterways. State capitals were identified and, because no two could be matched, eventually eliminated. The Education Directory (U.S. Office of Education) was used to locate colleges of 3,000 or more enrollment which offer graduate degrees. Business importance ratings, trade ratings, economic activity classifications, special activity information, and manufacturing value added index numbers were taken from the Rand McNally City Rating Guide.

Matched Pairs

After the information was recorded, the task of matching freeway cities with nonfreeway cities by pairs began. To limit any influence of city size on growth rate differentials, the population gap between the two cities of a pair was generally held to 15 percent.

In a few instances, e.g., where two cities were otherwise exceptionally well matched, larger differences (23 percent in one case) were permitted, but the median population difference for all pairs was much lower—9 percent. To restrict geographic influences (markets, resources, wages, etc.) the second city of a pair was drawn from the same state as the first or from the near side of an adjacent state. Primary emphasis was placed not on the state but on airline miles of separation between paired cities. This was generally limited to 175 miles in the eastern states, 200 miles in the central states, and 250 miles in the West. Nationally, the median separation between paired cities was 102 air miles.

The matching of transport characteristics was fairly strict. Both cities of a pair (the freeway city and the nonfreeway) or else neither had to have airline service; and if neither had it, both or neither had to have an airport. Again, both cities or else neither had to be located on a navigable waterway. Ports were always paired with ports, non-ports with non-ports. The rail service ratings were too inadequate to apply rigorously, but were used judgmentally in combination with other factors to determine the best match where there was an option. Likewise, although major dissimilarities were not permitted, the economic and special activity ratings were chiefly used judgmentally; anything approaching identity on a large number of points would have ruled out substantially all combinations. However, for college and resort towns, identity on these two factors was required.

Balancing the Groups

Small population differences for individual pairs could (and sometimes did) cumulate to produce large differences in the aggregate, and two-state pairs could lead to unequal representation for a state in the freeway group as compared to the nonfreeway. To prevent such imbalance, the original pairings were refined, region by region.

Both for balancing and for subsequent analytical purposes, the country was divided into eight regions: Northeast, Southeast, East Midwest, West Midwest, South Central, North Central, Northwest, and Southwest. Freeway and nonfreeway city populations were totaled by region, and city counts were tallied for each state. Certain pairs were then eliminated and others reconstituted in order to bring the freeway and nonfreeway totals into agreement. Under the final pairings, the largest regional population difference (freeway vs nonfreeway) was 0.6 percent, while the national difference was 0.004 percent. Moreover, each state had the same number of cities in each group, subject to the reservation that up to one freeway and one nonfreeway city from a state could be counted in an adjacent state if the city was close to the state line.

The final pairings included 212 cities (106 pairs). All but 13 were between 10,000 and 50,000 in population, the smallest and largest being approximately 6,400 and 56,600, respectively, and the median population standing at about 15,000. The Southeast had the most pairs, 20, and the Northwest the least, 6. All but one of the remaining regions yielded 14 pairs. Usable cities were found in all states but Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, Wyoming, Utah, and Nevada.

Measuring Growth

The Census of Manufacturers proved to be the only satisfactory source of manufacturing growth data for cities. The two most recent manufacturing censuses for which data have been published were conducted in 1958 and 1963; hence the growth period became 1958-63. More recent figures would be desirable, yet the statistically significant findings obtained for the relatively early period indicate that the data are adequate.

Among the many measures of manufacturing activity available in the Census reports, manufacturing employment is the one most relevant to the purposes of this study: jobs are what economic development programs ultimately seek to provide. Manufacturing employment therefore became the basic measure of growth. As a check on the validity of the employment data, the number of manufacturing plants with 20 or more employees was also recorded. Both figures—employment and plants—exclude manufacturing activity located beyond city limits but are otherwise reliable.

The basic statistic used in analyzing and comparing manufacturing growth was per capita increase in manufacturing employment. For each city the net change in employment was obtained by subtracting 1958 employment from the 1963 total. The difference, or absolute change, was then converted to a rate to permit cities differing in size to be combined and compared. Dividing a city's net change by its 1960 population gives the per capita increase or decrease. The per capita figure was deemed better than a percentage increase for analytical purposes because the latter figure is overly sensitive to variations in 1958 employment. Since resources did not permit highly refined analysis of the data on plants, the net increase was the only city value computed in connection with the new plant measure.

Statistical Analysis

In order to allow computation of probability levels, the mean was used as the primary measure of central tendency. In other words, the per capita employment growth rates for individual cities were averaged. Freeway and nonfreeway means were computed separately in all instances. This was done for the 106 pairs combined and for numerous breakdowns, e.g., by region and population interval. The freeway and nonfreeway means were then compared to determine whether and under what circumstances significant differences could be found. Statistical significance levels were computed on the basis of T distributions (non-normal). For changes in number of plants, a different measure of central tendency, the median, was used, and significance levels were not examined.

Supplementary analyses employing correlation coefficients were also prepared. First, in order to examine more closely the relationship between growth and distance to freeway, growth vs distance correlations were computed for hundreds of curvilinear functions of both growth and distance. These correlations were run initially for all 106 pairs and then repeated for significant regional groupings. Here the primary intent was to discover the precise nature of any relationship between the variables—type of curve, rate of attenuation in growth with increasing distance, etc. Second, to investigate the possibility that growth rate differentials resulted from uncontrolled differences in 1958 manufacturing levels between the freeway and nonfreeway cities, growth was correlated with 14 industry variables, e.g., 1958 total and per capita manufacturing employment. Partial correlations between distance and growth were then computed with manufacturing controlled. Finally, separate freeway and nonfreeway correlations for growth vs manufacturing were computed.

FINDINGS AND ANALYSIS

The study findings indicate that modern highways do significantly affect manufacturing growth but not in all situations. Freeway cities grew faster only in regions where traffic flow along regular highways is seriously impeded. And within these regions, the freeway influence was evident largely in cities which were either above a certain size or else had airline service. The availability of good rail service or water carrier service did not affect the response to freeways. In the significant categories, the freeway influence tapered off in curvilinear fashion with increasing distance and substantially disappeared beyond about 10 miles. Local industry had little effect on growth-distance correlations.

All Cities Combined

The first statistical analysis compares all 106 freeway cities with all 106 nonfreeway cities. To repeat, the basic measure of growth is the mean of the per capita manufacturing employment increase values for individual cities. In the findings below, this measure is expressed as new jobs per thousand capita. For the freeway group the average growth rate was 19; for the nonfreeway group it was 16. This small difference is significant only at the 0.67 level of statistical probability. That is, a difference this large could occur by chance 67 percent of the time, in two experiments out of three. Looking at the supplementary measure of growth, median increase in large plants (20 or more employees), both groups grew by the same amount. These findings support the conclusion that, for cities in general, proximity to the Interstate System did not significantly influence urban manufacturing growth during the period 1958-63.

Regional Breakdowns

When the city pairs were broken down by region, significant differences began to appear. Large employment growth rate differences favoring the freeway group were found in three regions. The freeway advantage was 52 to 31 in the Southeast, 30 to 19 in the East Midwest, and 25 to 4 in the Northwest. In the other five regions the nonfreeway cities exhibited small advantages. The results are of particular interest be-

TABLE 1

NATIONWIDE AND SELECTED REGIONS

Region	Pairs	Freeway	Non-Freeway	F - NF	Significance
Nationwide					
Employment	106	19	16	3	0.67
Large plants		1	1	0	
SE + EMW + NW					
Employment	40	43	23	20	0.04
Large plants		2	2	0	
SE + EMW					
Employment	34	46	26	20	0.07
Large plants		2	2	0	

cause of the tentative support offered to the hypothesis that freeways have an impact in regions of dense population and hilly terrain, i.e., regions where the traffic flow benefits of freeways are greatest. Among such regions, only the Northeast failed to show a strong freeway advantage. (Lack of city pairs prevented any findings for the Rocky Mountain area and the lower two-thirds of California.) And, to anticipate, even in the Northeast the freeway cities displayed faster growth when the analysis was confined to larger cities. The relatively poor performance of freeway cities in the Northeast may have been influenced by the region's status as the slowest growing region of the country; growth rate differentials are difficult to detect where little growth occurs.

Because of the small number of cases in any particular region, significance levels were not computed for single regions. However, two multiregion combinations were tested for significance. First, the three freeway sensitive regions—Southeast, East Midwest, and Northwest—were combined. Here the freeway cities enjoyed a 43 to 23 advantage in employment growth rate. The difference between means was significant at the 0.04 level. Second, because there are theoretical objections to including a noncontiguous region (the Northwest) in the combination, a separate analysis combining only the Southeast and East Midwest was made. This time the freeway advantage was 46 to 26, significant at the 0.07 level. (The lower level of significance reflects the smaller number of cases on which the finding is based.) The findings for the nation as a whole and for the two regional combinations are summarized in Table 1.

Other variables having a catalytic effect on freeways must still be considered, but the findings begin to suggest that in certain regions freeways significantly influence manufacturing growth. In the eastern United States, dense population means heavy traffic, with towns causing relatively frequent interruptions. At the same time, rough topography produces numerous hills and curves which limit the sight distance for passing and otherwise restrict speeds. Eastern freeways therefore offer extra large advantages, particularly where trucks moving on grades are concerned. But to the west beyond the Appalachians, the Great Plains appear. The terrain becomes flatter and, simultaneously, population and traffic thin out. Freeways still help, but not as much.

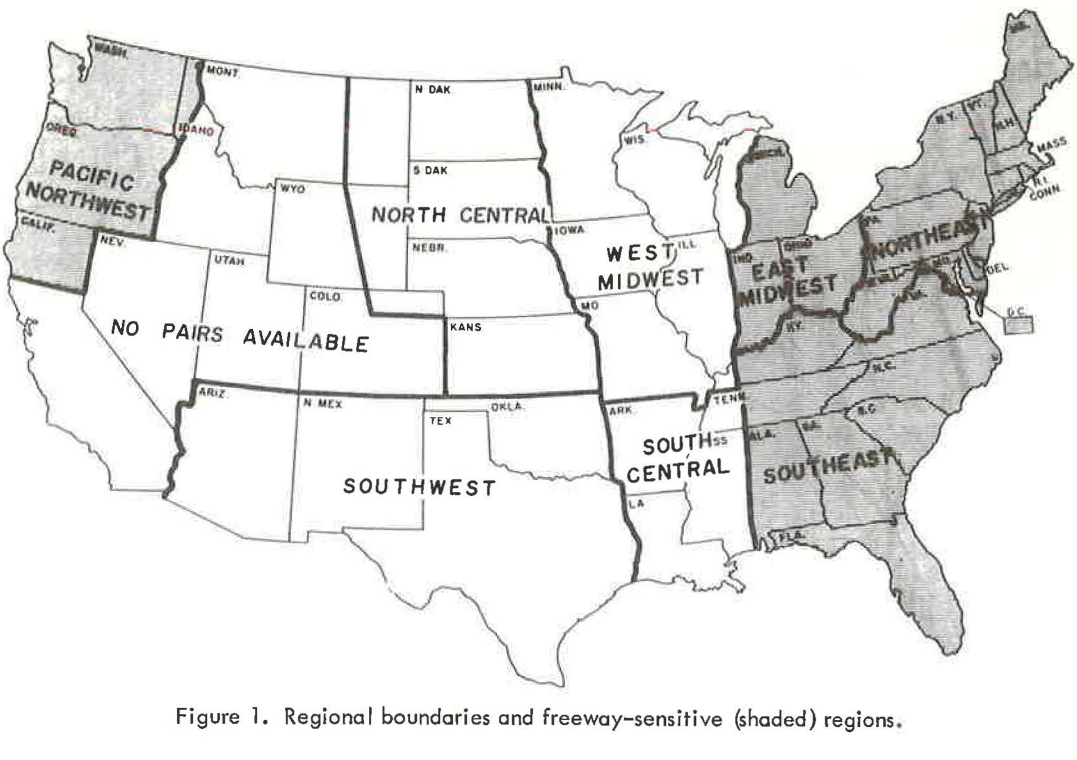

Figure 1. Regional boundaries and freeway-sensitive (shaded) regions.

On the West Coast, traffic again becomes heavy and topographical irregularities reappear. The findings thus display a logical pattern for the hypothetical freeway influence. (The West Coast findings are limited to the Northwest—Idaho, Washington, Oregon, and northern California—because the abundance of freeways in California made it impossible to obtain city pairs from central and southern California. Rocky Mountain pairs are also lacking.)

Population

When the study cities were broken down by population intervals, it became obvious that the freeway group had an advantage chiefly among the larger cities. Experimentation showed the 16,000 population level to be the optimal breaking point for differentiating between cities which respond to freeways and those which do not. Obviously, 16,000 is not a magic number but merely indicates a tendency for industry to respond to freeways as the cities they serve grow larger. This tendency, though, is consistent from region to region among the four regions. And it is further confirmed by the findings of two other studies conducted in conjunction with the present one. In a study comparing airline with nonairline cities, it was found that air service significantly (confidence levels as high as 0.01) influences growth in cities above 19,000. A waterway study showed that waterway cities on the Mississippi-Ohio River System grew significantly slower (0.06 level) than comparable nonwaterway cities (possibly because of flood hazards) but only among cities above 15,000. The likely explanation for the consistent influence of population is that large firms and branch plants, which tend to locate by more nearly rational criteria, seek locations in cities above roughly 15,000, whereas small city industry has a higher proportion of "home town" firms.

Nationwide, freeway cities above 16,000 outgrew their nonfreeway mates 14 to 5. Data for individual regions indicate, however, that the freeway advantage was largely confined to the three regions previously identified as sensitive to freeways plus the slow-growing Northeast. In the West Midwest and South Central regions, freeway cities above 16,000 actually showed a slight disadvantage. The shaded area in Figure 1 defines the four freeway sensitive regions. The addition of the Northeast (beginning with West Virginia) to the sensitive regions is important, for it overcomes the one exception to the evidence supporting the traffic flow hypothesis. (The Northeast freeway advantage was only 0.5 to -0.2, hardly significant in itself but at least consistent with the assumption that freeways boost growth where nonfreeway traffic is severely impeded.)

Pairs in which both cities were above 16,000 population were tested for significance for several regional combinations. These are shown in Table 2. For the four sensitive regions combined, the freeway advantage was 27 to 4, significant at the 0.03 level of probability. The Northeast had so many cities which experienced losses that its data are not entirely meaningful: 8 of 16 Northeast cities (3 of them freeway) declined. If this region is therefore dropped from the combination, the freeway advantage goes up to 34 to 6, significant at the 0.02 level. The freeway cities also develop an appreciable lead in new plants. If the noncontiguous Northwest is also dropped, the freeway

TABLE 2

PAIRS ABOVE 16,000 POPULATION

Region	Pairs	Freeway	Non-Freeway	F - NF	Significance
NE + SE + EMW + NW					
Employment	26	27	4	23	0.03
Large plants		2	1	1	
SE + EMW + NW					
Employment	19	34	6	28	0.02
Large plants		3	1	2	
SE + EMW					
Employment	15	38	7	31	0.04
Large plants		4	1	3	

margin rises to 38 to 7, but with fewer cases the significance level falls to 0.04. Because the freeway group has a relatively greater advantage in new jobs than new plants, part of the job gain seems related to established firms.

For cities below 16,000 in the three more sensitive regions, the freeway group still grew faster, 52 to 38. But the difference, covering 21 pairs, is significant only at the 0.37 level. Viewed in the context of the highly significant difference for cities above 16,000, the below 16,000 difference cannot be entirely discounted. A cautious conclusion would be that there is weak evidence of a freeway impact among smaller cities but that any such impact is relatively mild.

Airline Cities

Economists have long suspected that cities with airline service grew faster: most business travel is by air, and it is known that some firms insist on locations where air service is available (e.g., to facilitate contact between branch plans and headquarters.) Indeed, the previously mentioned companion study comparing airline and nonairline cities shows the airline group growing significantly faster, particularly in the South and West, for pairs above 19,000 population. This suggests the possibility that industry is attracted to freeway cities only, or especially, if there is concomitant air service. To examine this possibility, airline pairs were broken out for separate analysis. (Remember, the two members of a pair are always matched on air service: both have it or else neither has it.)

Nationwide, the airline cities located on freeways grew faster (12 vs 4) but not significantly. However, as in the case of cities above 16,000, the freeway group did significantly better than the nonfreeway in the four sensitive regions. The airline pair findings are summarized in Table 3. It shows substantial freeway advantages for all regional combinations, with the significance level reaching 0.03 for the three region combination (Southeast-East Midwest-Northwest).

Is this finding due to the fact that most airline cities are above 16,000? Conversely, do freeways affect larger cities simply because most of them have air service? Further analysis suggests that the catalytic effects of population and air service are substantially independent of one another. A 26 to 10 employment growth rate advantage held by the freeway group for 12 nonairline pairs above 16,000 in the four regions points to the independence of population. A majority of the freeway cities outgrew their mates

TABLE 3

AIRLINE PAIRS

Population and Region	Pairs	Freeway	Non-Freeway	F - NF	Significance
Population Unlimited					
NE + SE + EMW + NW					
Employment	18	27	2	25	0.04
Large plants		1	0	1	
SE + EMW + NW					
Employment	13	40	7	33	0.03
Large plants		1	0	1	
SE + EMW					
Employment	8	51½	8	43	0.07
Large plants		2½	0	2½	
Above 16,000					
NE + SE + EMW + NW					
Employment	14	27	-1	28	0.06
Large plants		-½	-½	0	
SE + EMW + NW					
Employment	10	39	2	37	0.05
Large plants		½	1	-½	
SE + EMW					
Employment	7	50	2	48	0.07
Large plants		4	1	3	

in each region. Air service's independence of population can be inferred from an even larger freeway advantage, 27 to -1, found among 14 airline pairs above 16,000 in the same four regions. Below 16,000 the freeway city grew faster in three of four airline pairs in these regions (the fourth case was a tie), giving freeway cities a 28 to 11 advantage. Corroborating evidence of the independent significance of air service as a freeway catalyst comes from the companion study of air service, which included eight eastern freeway pairs (both the airline and the nonairline member of each pair were freeway cities). Freeway-plus-airline again proved an effective combination, though this time in comparison with freeway-but-no-airline: the airline advantage was 27 to -1, significant at the 0.09 level, for all eight cases and 19 to -3 for five cases below the air study's critical population level of 19,000. In short, freeways stimulate growth even in smaller cities if they are also served by air.

The findings for airline cities above 16,000—the two catalysts operating in combination—are of particular interest. Cities with both catalysts grew markedly faster when located on a freeway (Table 3). For the two region combination, all seven freeway cities outgrew their mates. This could happen by chance 1 time in 128.

Combined Categories

If, in the sensitive regions, either a population above 16,000 or airline service tends to enable manufacturing growth to respond to freeways, one would expect results of even greater statistical significance to be obtained from a supercategory including city pairs from both groups. The logic of this combination is simply that most firms which locate rationally seem to demand not only good highway connections but (a) the suppliers, services, amenities, and labor supply found in a larger city, (b) air service, or (c) both. Table 4 indicates what happens when all pairs in the greater than 16,000 range are combined with the remaining airline city pairs.

As anticipated for the larger numbers of cases, probability levels reach their peaks for all regional combinations. When the Northeast is dropped from the picture, a difference between means which could occur by chance only once in 100 experiments appears. The 1 percent level of probability represents the norm frequently applied in conservative statistical interpretations. Five percent, however, can ordinarily be regarded as significant, and even a 10 percent level evokes interest. Therefore, assuming that the principal nonhighway variables have been adequately controlled and that the freeway and nonfreeway groups do not differ appreciably with respect to some unrecognized factor of significance, the findings appear to justify the conclusion that freeways aid manufacturing growth under certain conditions.

It is interesting to see what happens when the freeway and nonfreeway cities in the four region combination (60 cities) are combined and ranked by growth rate. Freeway cities dominate the top quartile, nonfreeway cities the bottom. The number of freeway cities declines in each successive quartile below the top, an impressive showing

TABLE 4

ALL CITIES OVER 16,000 PLUS AIRLINE CITIES UNDER 16,000

Region	Pairs	Freeway	Non-Freeway	F - NF	Significance
NE + SE + EMW + NW					
Employment	30	27	5	22	0.02
Large plants		2	1	1	
SE + EMW + NW					
Employment	22	36	8	28	0.01
Large plants		3½	1	2½	
SE + EMW					
Employment	16	40	10	30	0.04
Large plants		3½	1	2½	

of internal consistency in the data. The following table shows how many cities of each group fall in each quartile.

Group	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Freeway cities	11	10	5	4
Nonfreeway cities	4	5	10	11

Rail and Water Carrier Categories

Additional categories which conceivably would respond to freeways are cities with or without good railroads or water carrier service. Cities with poor rail service might experience "catch-up growth" with the advent of a freeway, with road becoming a substitute for rail. Alternatively, firms might demand excellence of both rail and highway facilities, or of both water and highway service.

Despite these possibilities, analysis of rail and water carrier breakdowns failed to show any unusual advantage for freeway cities. To test the rail hypothesis, pairs in which both cities had rail service in only one or two directions (all had at least one rail line) were compared with pairs having rail service in three or four directions. This was done nationwide and for the four sensitive regions. For both geographic comparisons, the difference between freeway and nonfreeway employment growth rates was about the same for both rail categories. Nationally, the freeway city advantage was 6 jobs per thousand capita for pairs with good rail service and 2 jobs for the poor service pairs. In the four regions, the comparable differences were 21 and 18. This seems to reflect the fact that almost all cities with poor rail service are below 16,000.

Only 5 waterway pairs (10 cities) were available for analysis, and three of these were outside the four sensitive regions. A comparison was nevertheless made. It showed both groups, freeway and nonfreeway, losing jobs. (Nine of the ten cities declined!) The freeway "growth" rate was -6, the nonfreeway rate -9. This is not a significant difference.

Distance to Freeway

The next relationship explored should prove of special interest to highway planners. It concerns how close a city must be to the nearest freeway exit (access point) to gain a manufacturing advantage, assuming there is an advantage to be gained. Two procedures were used to explore the relationship between distance (road mileage from city to nearest freeway access) and manufacturing employment growth rate.

Under the first test, the 30 sensitive pairs (Table 4: four regions) were separated into two categories based on the nonfreeway city's distance from the nearest freeway. In one category were placed 8 pairs in which the nonfreeway city's distance was 16 to 25 miles; into the second went 22 pairs with a nonfreeway distance on more than 25 miles. The more distant nonfreeway cities actually did better relative to their freeway mates than the closer-in nonfreeway cities. (Considering geographic disparities involved, the difference was not significant.) Moreover, all 8 nonfreeway cities in the 16- to 25-mile category grew more slowly than their freeway mates. The odds against this happening by chance are 256 to 1.

Correlation analysis provided a second and more precise test of the relationship between distance and growth. The two variables were correlated for (a) nonfreeway cities alone and (b) freeway and nonfreeway cities combined. For each category, separate correlations were run using all 106 pairs and then just the 30 sensitive ones from the four regions. In each situation hundreds of curvilinear functions of distance, as well as the unadjusted and dummy (explained below) values, were correlated with growth and functions of growth. For example, growth and its log were correlated with 50 powers of distance ranging from $D^{0.1}$ to $D^{5.0}$. The idea was to identify and measure any curvilinearity in the relationship.

If proximity to a freeway has any influence on nonfreeway cities (defined as more than 15 miles from a freeway), there should be a reasonable correlation (r) between growth and distance for nonfreeway cities. Actually, the highest r's were quite low: -0.23 (log G vs $D^{1.4}$) for all 106 nonfreeway cities and -0.15 (log G vs $D^{2.0}$) for the 30 nonfreeway cities from the sensitive pairs. These values do not suggest that freeways appreciably affect cities more than 15 miles away.

For freeway and nonfreeway cities combined, one can theorize that growth will decline with increasing distance according to the pattern of a normal probability curve: variations in distance should have little effect over the first few miles, but growth should then begin to decline more rapidly until distance approaches the limits of its influence, after which the curve should flatten out again (so that growth does not become highly negative at extreme distances). This bell shaped pattern is just what materialized. Although no significant r's were found for the nationwide grouping of 212 cities, some fairly good r's appeared in the sensitive categories. The distance function producing the highest r's was based on the probability curve relationship $y = \exp\left(-\frac{D^2}{2\sigma^2}\right)$, where y is a function of distance, e = 2.718, D is distance (miles), and σ is an experimental standard deviation varying from one to fifty on successive iterations.

The 30 pair findings are summarized in Table 5. Because observers may be interested, three r's are shown: the linear r for growth vs distance (unadjusted), the r produced by a dummy variable equal to 1 for freeway cities and 0 for nonfreeway, and the r for the normal curve function described. The σ column gives the standard deviation at which the maximum r, shown under "Curve," was obtained. The "Significance" column shows the degree of probability that the r under "Curve" differs significantly from zero. Separate findings are again presented for three regional combinations. The "Full Correlation" line under each regional heading shows the r's between distance and growth. Since regional influences, particularly the Northeast's lack of growth as it affects growth in Northeast freeway cities, tend to obscure the relationship, the Type A entries have been added to show partial r's resulting when ten state variables are controlled. Three other sets of partial r's for as many combinations of 10 state and local variables being controlled follow. These are based on an 80 variable multiple

TABLE 5

GROWTH CORRELATED WITH DISTANCE TO FREEWAY: SENSITIVE REGIONS
(All Cities Over 16,000 plus Airline Cities Under 16,000)

Region	Cities	Linear	Dummy	Curve	σ (miles)	Significance
NE + SE + EMW + NW	60					
Full correlation		-0.26	+0.30	+0.33	5	0.011
Partial: Type A		-0.29	+0.40	+0.46	4	0.001
Partial: Type B		-0.32	+0.46	+0.48	5	0.001
Partial: Type C		-0.27	+0.44	+0.43	7	0.001
Partial: Type D		-0.30	+0.48	+0.48	6	0.001
SE + EMW + NW	44					
Full correlation		-0.27	+0.38	+0.40	5	0.008
Partial: Type A		-0.32	+0.47	+0.54	3	0.001
Partial: Type B		-0.25	+0.51	+0.52	6	0.001
Partial: Type C		-0.20	+0.43	+0.42	7	0.005
Partial: Type D		-0.25	+0.46	+0.46	6	0.005
SE + EMW	32					
Full correlation		-0.23	+0.36	+0.41	4	0.02
Partial: Type A		-0.29	+0.40	+0.50	3	0.01
Partial: Type B		-0.18	+0.44	+0.45	5	0.02
Partial: Type C		-0.11	+0.38	+0.40	5	0.03
Partial: Type D		-0.30	+0.33	+0.47	2	0.02

Type A: controls 10 state variables—4 forced and 6 free (free means computer selects highest partial r at each step of regression series).
Type B: controls 9 state variables (4 forced, 5 free) plus best local variable, viz., value added per capita weighted by state growth rate.
Type C: controls 4 best state, 3 local industry, and 3 free variables.
Type D: controls 10 free variables, state and local (computer selects all).

regression analysis and relate primarily to the analysis of industry and growth, which follows.

The findings in Table 5 support the theory that freeway-induced growth tapers off with increasing distance from a freeway in a manner described by the positive side of a normal probability curve peaking at zero miles. Depending on the regional grouping and type of r examined, this curve has a standard deviation of from 2 to 7 miles. A curve with a standard deviation of 5 miles (the average reading) means that if the growth-distance relationship were perfect, a growth rate of 100 (height of ordinate) at 0 miles would be associated with rates of 61 at 5 miles, 14 at 10 miles, and 1 at 15 miles. Two standard deviations look like the approximate distance beyond which the freeway influence becomes insignificant. Hence one might say that freeways have little influence beyond about 10 miles, or to be punctilious, beyond an indeterminate distance between roughly 5 and 15 miles.

Industry and Growth

Is a city's manufacturing employment growth rate affected by the amount of industry with which the city started? If so, any uncontrolled differences (freeway vs nonfreeway) in 1958 manufacturing employment, or perhaps some other measure of industry, could have distorted the study findings. That is, the freeway cities might have benefited from a favorable industrial posture at the start of the 1958-63 growth period. Further analyses were undertaken to check this possibility.

First, with regard to the specific possibility that employment was not adequately controlled, 1958 manufacturing employment was totaled for each of the two groups. This was done both for all 106 pairs and for the 30 pairs (Table 4: four regions) in the freeway-sensitive categories. Nationally, the difference was one percent (freeway, 234,659; nonfreeway, 231,889). For the 30 pairs it was 4 percent (freeway, 114,577; nonfreeway, 119,675), the advantage going to the nonfreeway group. In short, whatever the significance of manufacturing employment as a stimulus to its own growth, the freeway cities did not enjoy a running start.

Next came a series of correlation tests. The first tests correlated two variables (1958 total manufacturing employment and 1958 per capita manufacturing employment) with growth. The tests covered the 212 cities combined and 17 breakdown categories. Generally low and frequently negative r's were encountered: for all 212 cities the r's correlating growth with employment and per capita employment were -0.03 and +0.22. But for certain geographic groupings the r's were significant: the Northeast showed one of -0.47 between growth and per capita employment, and the other regions combined showed a comparable r of +0.39. (Heavily industrialized cities had greater losses in the Northeast and greater gains elsewhere.)

More rigorous tests were then conducted using the 30 sensitive pairs. These and all subsequent correlation analyses employed a stepwise regression program equipped to handle 80 variables. Besides the dependent variable (city growth rate) the variables included 10 functions of distance to freeway, 21 other local variables (with 16 relating to industry), and 48 state variables. The distance functions were those covered in Table 5 and included the eight probability curve functions for σ = 2-9. The state variables included five growth measures plus other values (e.g., temperature) shown by independent research to be highly correlated with state growth.

Interesting r's appeared. For the 60 cities the r between growth and manufacturing value added (a measure of industrial output) per capita was +0.38. Further analysis showed even higher positive r's between industry and growth (reaching +0.62 for value added per capita) among the 44 cities in the three fast growing regions (SE + EMW + NW) offset by negative r's (reaching -0.63 for employment per capita) in the Northeast, where most cities either declined or grew very slowly. Thus, when value added per capita was weighted by state 1958-63 per capita employment growth rate (negative for some Northeast States), the 60 cities produced an r of +0.62 between growth and the weighted variable—well above the unweighted +0.38. The "sensitive" cities thus repeated the 212 city pattern whereby cities with the most industry registered the biggest gains and losses, depending on whether their states grew or declined.

This finding invites doubt as to whether very similar employment totals between the freeway and nonfreeway groups fully rule out possible effects from industrial disparities. The next analysis tackles this question. It involves partial r's between growth and the distance variables. Each partial r entails simultaneous control of ten variables, differing from test to test. First, the Type A partials described in the distance analysis (ten regional variables controlled) were compared with some Type B partials, which substitute weighted value added per capita for the weakest state variable. The findings in Table 5 show that controlling the strongest industry variable has little effect: the Type B partial r for the dummy variable is actually higher than the Type A partial for all three regional groupings, and the optimal curvilinear r for type B is higher for the four region combination. Second, additional partial r's were computed based on more extensive control of local variables. This time four state and three local industry variables were forced into the stepwise regression program to insure reasonable control of state and industry disparities, and three additional variables were freely selected by the computer as those with the highest partial r's (but with distance suppressed) going into each of the last three steps.

The ten variables "partialed out" in the four region analysis (Table 5) were (1-2) state 1958-63 per capita and percentage increases in manufacturing employment, (3) state January mean temperature times state ratio of income to value added, (4) $\sqrt{(50 - \text{latitude})(\text{longitude} - 65)}$, (5) manufacturing employment, (6) value added, (7) value added per capita weighted by state per capita employment growth rate, (8) number of plants with 20 or more employees, (9) ratio of manufacturing employment to value added, and (10) Rand McNally business importance rating. All values are local except where "state" is indicated. Table 5 shows that the new partials, designated Type C, were slightly lower than the Type B ones yet higher than the original correlations. Finally, to place things squarely on an objective basis, the computer was given free rein to choose all ten controlled variables (variable with highest partial enters regression equation at each step). The resulting Type D partials (Table 5) fall right in the middle of the range of values for Types A, B, and C—still above the original r's. These findings indicate that the relationship between freeways and growth is not due to a coincidence of freeways and industry.

Freeway Effect on Industry's Effect

The r's between growth and distance to freeway are lower than might have been anticipated considering the rather large differences between means examined earlier. And this discrepancy introduces a final industry analysis, again involving r's between growth and the industry variables. This time the freeway cities were separated from the nonfreeway cities for the 44 cities from the three fast-growing regions. (The Northeast was omitted because its positive r's between losses and industry tend to cancel the positive r's between growth and industry in the other three regions, obscuring high correlations.) Full and partial r's were computed for the 14 local industry variables; the

TABLE 6

GROWTH CORRELATED WITH MANUFACTURING: SE + EMW + NW
(All Over 16,000 plus Airline Cities Under 16,000—22 Pairs)

Manufacturing Variable	Freeway Cities		Nonfreeway Cities	
	Full r	Partial	Full r	Partial
Mfg. employment	+0.69	+0.78	+0.15	+0.15
Mfg. value added	+0.79	+0.83	+0.18	+0.24
Mfg. employees per capita				
Unweighted	+0.78	+0.81	+0.33	+0.26
Weighted by state growth	+0.79	+0.80	+0.31	+0.26
Value added per capita				
Unweighted	+0.85	+0.90	+0.32	+0.25
Weighted by state growth	+0.87	+0.93	+0.30	+0.26

partial r's entail control of the four state variables listed above plus population and Rand McNally business importance rating.

Highly impressive differences between the freeway and nonfreeway r's appeared. The freeway cities generated numerous very high r's of up to +0.93 (partial r for per capita value added weighted by state 1958-63 manufacturing employment growth per capita); none of the nonfreeway r's rose above +0.33. Table 6 summarizes the r's for the six highest industry variables. Considering that the freeway and nonfreeway groups are approximately equal in aggregate manufacturing employment, the findings in Table 6 strongly suggest that freeways affect growth indirectly as well as directly. Existing industry is helped to expand—the more industry, the more expansion—and/or to attract other industry. Part of the freeway impact shows up not in the distance r's but in higher industry r's.

CONCLUSIONS

The study findings appear to justify several conclusions. Because the 1958-63 period studied may be too early to mirror the full impact of the Interstate System and in view of the limited number of cities available for analysis, these conclusions may be regarded as tentative. Broader effects may become evident as the System nears completion.

1. Freeways aid manufacturing growth, but only under certain conditions, in the cities which they serve. Rapid, low-cost motor freight attracts industry and facilitates increases in manufacturing employment.

2. The freeway impact is confined to regions characterized by dense population and uneven terrain—regions where freeways offer relatively substantial time savings. These regions embrace (a) all eastern states beginning with Indiana and Alabama and (b) the Pacific Northwest states. General industrial stagnation in the Northeast, beginning with West Virginia, limited the freeway impact in that region. Lack of data precludes findings for the Rocky Mountain states and central and southern California.

3. In the four sensitive regions, freeway related manufacturing gains are mainly confined to cities above 16,000 or (regardless of population) with air service. Many firms desire not only good freight transportation but good personal transportation and other medium-sized city amenities.

4. The manufacturing impact of freeways is not dependent on or affected by the presence or level of rail or water carrier service.

5. The relationship of growth to distance-to-freeway is described by a probability curve (bell shaped) peaking at 0 miles and with a standard deviation of roughly 5 miles. Benefits do not accrue to cities located more than about 10 miles from the nearest freeway.

6. Although growth is significantly correlated with prior industry, the freeway advantage was not thereby influenced: freeway cities started with slightly less industry, and partial correlations between distance and growth with industry controlled are higher than the original correlations.

7. Freeways probably stimulate existing industry as well as attracting new plants, for (a) the ratio of freeway to nonfreeway gains is higher for employment than new plants and (b) existing industry has a much higher correlation with growth in freeway than in nonfreeway cities.