Land Use Goals in Transportation Policy: The Case of Central City Decline

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I. Introduction

Knowledge about the interactions between transportation and land use is in a peculiar state. It is widely agreed that influences in both directions exist and that they are of considerable significance. A great deal of attention is paid to their policy implications, and the current battle cry of “joint development” pays tribute to the importance placed upon careful and enlightened guidance of these powerful forces. Yet, when it comes to isolating and quantifying the exact influences involved, there is wide and fundamental disagreement within and among the communities of researchers, planners, operators, business leaders, and politicians.

This paper deals with one side of the two-way interaction: the influence of transportation improvements on land use. The resolution of the uncertainties surrounding this issue is of major importance to transportation policy, since claims about the existence or lack of desirable effects on urban structure play a major role in deliberations over the extent and types of transportation facilities which are most desirable. In order to narrow the question to one of manageable proportions, I focus here upon the role of transit improvements in the continuation or abandonment of the widespread decentralization of jobs and population characterizing metropolitan areas in the United States.

The outlines of the debate may be quickly sketched. Transit advocates argue that transit improvements, primarily fixed guideway projects, are an important consideration in the evaluation of such investments. Dramatic claims have been made, such as Warren H.eath’s statement that $10 billion in land appreciation was attributable to the original $67 million Yonge Street subway in Toronto [15, p. 42]. These arguments have been effectively used by proponents of most of the recent rapid rail proposals [6].

On the other hand, a number of academic economists and planners, doubting the wisdom of expensive fixed guideway investments, have implicitly or explicitly minimized this argument. In widely publicized writings, Meyer, Kahn and Wohl [16], Hamur [6], and Webber [25] have argued that the forces producing suburbanization are too strong to

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The outlines is grateful to Katherine Bradley, Doug

Diamon, Anthony Downs, Jane Eisenhauer, David Herrold, Yves Kuriak, and Richard West for help

ful comments. The work described here was supported by grants from the Ford Foundation, the Urban Mass Transportation Administration, and the Federal Highway Administration to the Brookings Insti

tution. The results and views expressed are solely the responsibility of the author, and should not be attributed to any of the above named institutions.
be counteracted with transit policies, and that fixed rail systems are in many cases unjustified. Hammer puts it strongly:

Neither the history of U.S. rail rapid transit centers nor the more recent experience in Toronto provides a basis for believing that urban areas now heavily dependent on the automobile can be transformed to fit the visions of frustrated urban planners yearning for living and travel patterns characteristic of the late nineteenth century. [p 177]

Perhaps the most thorough and tightly reasoned review of the subject is by Gómez-Ibáñez [4], who argues that the various land use incentives are so conflicting, and our knowledge of them so imperfect, that land use decisions need enter as a strong consideration in determining urban transportation policy.

Yet all these authors recognize that, depending on circumstances, the land-use effects of transit projects may be significant. It is asking a lot of those whose livelihoods or political fortunes depend on the small-area impacts of such projects to ignore whatever evidence they can muster. Furthermore, this agonistic assessment poses a quandary for urban researchers, since the single most influential model of urban structure has transportation costs at its very heart. Thus, it is the thesis of this paper that, regardless of the advice of researchers, decisions about transportation projects will and should take into account their land-use implications. It follows that it is vital to bring to bear the best evidence possible.

A number of approaches suggest themselves for this purpose, all of them admirably reviewed both by Gómez-Ibáñez [4] and by Ingram [10]. A strictly empirical approach would directly utilize the findings of the many studies of land use before and after the implementation of transit improvements in North American cities. Their results, however, are ambiguous. After a thorough review of rapid transit projects in nine cities, Knight and Trygg conclude that significant impacts have occurred in some but not all cities, and that they have generally occurred only when accompanied by favorable complementary factors including explicit public land-use policies.

As for theoretical approaches, the widely used general equilibrium models of urban structure are suggestive but, as Gómez-Ibáñez stresses, imply offsetting effects. While downtown accessibility favors central job locations, improved radial movement to and from the suburbs encourages residential decentralization. Numerical simulations within the general equilibrium framework, such as by Mills [17], are also suggestive, but are designed more to explain existing urban structure than to predict impacts from a change at a specific point in time.

A more appropriate theoretical framework for our purpose is a dynamic one, in which changes in location and land use are explained by transportation and other factors. Progress along these lines has been made in the form of both large-scale simulation models [11], and more limited empirical investigations [7, 20]. The approach adopted here is dynamic in this sense. After quantifying the various offsetting incentives created by a particular transit improvement in monetary terms, I bring to bear evidence on the effects of such incentives on the dynamic process of suburbanization. In the background is a model of decentralization as a disequilibrium process which proceeds at a rate proportional to the extent of disequilibrium. That is, the rate of outmigration is a direct function of the incentives on firms and households to relocate outside the central city. This approach is best suited to cities currently in decline, since we can consider policy-induced incentive changes as small perturbations in an underlying disequilibrium situation, and the proportionality assumption can be thought of mathematically as a first-order approximation to the true response. The argument is made here by means of a case study of one such city, Cleveland, which has been performed in collaboration with K. Bradbury and A. Dornan.

The empirical evidence on which the analysis is forced to rely is sketchy at best, and the quantitative estimates should be regarded as illustrative orders of magnitude, not as detailed planning tools for any specific transit program in the Cleveland area. This is particularly true of the estimate of the net result of offsetting forces, each of whose measurement is subject to independent error. Furthermore, the usual limitations of a single case study apply. Nevertheless, I believe the qualitative conclusions elaborated in Section IV are both reliable and of wide applicability.

II. Simulation Procedure

Major Offsetting Effects

It is first necessary to identify the various incentives which are claimed to have the offsetting effects making this topic so filled with controversy and uncertainty. In the process, it will perhaps become clearer just how complicated the problem really is.

First, the construction and operation of a transit facility has a direct local stimulus effect on jobs. Critics rightly note that the same effects arise from building pyramids or parking parks, and thus cannot be attributed specifically to transit. Nevertheless, they are evidently foremost in the minds of local decision makers, and in any event must be taken into account in a comparison with other policies aimed at revitalizing cities.

Second, a transit system which facilitates trips to the city's central business district (CBD) makes that a more attractive location for business, since both workers and customers will find it easier to get there. Insofar as intrametropolitan location is concerned, it is reasonable to suppose that the labor supply and customer demand faced by CBD firms are highly elastic, so that in the short run most of the average transport cost savings are captured in the form of higher profits. In the longer run, the supply of firms is also elastic, but it is, in fact, precisely this response (in a dynamic setting) which I attempt to measure as a function of the short-run profit differential.

Third, a radial transit system changes relative transportation costs for city and suburban residents. Even if the average cost saving is captured by downtown firms, the differential depending on residential location sets up incentives on households. The usual expectation is that a reduction in transport cost favors suburbanization, and there is little doubt of this in the case of highways. For transit, however, the situation is more complicated. Whereas the change in relative transport costs for those living at different distances from downtown clearly favors the suburbs, the change in relative costs for those using different modes favors transit users, who are substantially more concentrated among city than suburban dwellers. On the other hand, the release of some highway capacity due to mode shifts makes auto travel somewhat easier as well, and this favors the suburbs. All these effects are taken into account in the simulation reported below.

Finally, it is worth noting a number of effects which are probably of lesser significance for determining the net impact on city revitalization, and are therefore neglected here. Local financing requirements, if not truly region-wide, might impose extra costs on the city and/or inner suburbs; however, this should be comparatively small if, as is usually the case, the local share is a small fraction of...
the total project cost. The profitability of firms outside the CBD is no doubt affected by a transit project, but in most cases by a much smaller amount than for CBD firms. In particular, any direct dispersive effect of radial improvements on jobs is neglected here, on the grounds that trips to suburban destinations are only slightly affected by the type of improvements considered. Similarly, I ignore the possibility that transit stations may stimulate suburban nucleation and foster the realization of agglomeration economies among suburban subcenters more competitive with the central city; this could be significant for rail systems, though the empirical evidence is mixed, but is probably of little consequence were systems which provide minimal service to reverse-direction or cross-suburban travel.

Parameters for the Quantitative Estimates

In order to assess the quantitative significance of these forces in a realistic setting, a set of specific parametric assumptions was applied to a hypothetical package of transit improvements in the Cleveland metropolitan area. The results were expressed in terms of deviations from a Base-Case scenario, which was developed in considerable detail to represent continuation of current underlying trends over the period 1975-1990, with no major policy initiatives. The Base Case can be summarized briefly as projecting slightly rising employment and households (but population) for the SMSA, and continuing sharp decline in all these measures for the city of Cleveland.

The simulations required a large number of assumptions, only the most important of which are summarized here. Considerable effort was spent to test alternative assumptions for realism with respect not only to transportation policies, but to a number of other policy packages as well. To estimate the extent of direct job creation, we used a study of transit projects in the Boston area performed by the U.S. Bureau of Labor Statistics [22]. Including 4% of "indirect" jobs, and assuming 25 percent of all jobs are displaced rather than new, the BLS study implies that primary job creation amounted to about 40 person-years per million dollars of construction expenditure, and 30 permanent jobs per million dollars of permanent annual operating cost.

To analyze shifts in employment in response to improved CBD profitability, we applied the disinvestment view stated above to a study of manufacturing plant location by Homer [5]. Homer estimated the profit differential to a typical manufacturing firm operating in Boston versus its suburbs at $416 to $596 per employee per year. This was in the early 1970's, a time at which manufacturing employment was leaving the city at a net rate of about two percent per year. Other types of business have left central cities more slowly, but they presumably suffer less of a profit disadvantage, due to their greater dependence on agglomerative economies provided by the central city; if anything, the smaller capital intensity of non-manufacturing firms probably makes them more responsive to changes in location cost differentials. One could, therefore, make the following interpretation. City-suburb profit differentials create an incentive for firms to exituate, the strength of which is measured by the Homer study at about 2 percent per year.

The net outmigration for every $1000 per employee per year in cost differential in 1977 prices. This gives a parameter which can then be applied to an estimate of the profit differential created by a transit project.

To estimate shifts in household location due to differential changes in transport costs, we focused solely on the work trip to downtown, and translated cost savings for such a trip into an equivalent annual housing cost reduction for an average family in the city or its suburbs. To measure the effect on household migration, we utilized a study by Frey [3] which estimated the influence of average household taxes, among other variables, on gross migration. Local government expenditu-

ers were not held constant by means of a school expenditure variable, and job localization was controlled for by including a variable measuring the extent of reverse commuting. Frey found that the proportion of intrametropolitan movers from the central city choosing a suburban location is reduced by 1.2 percentage points for every increase of 0.1 in the ratio of suburban to central-city taxes per household. Similar estimates on immigrants showed no statistically significant effect of household taxes and so were ignored. To apply this result, we projected the annual tax cost for a typical SMSA household locating in a city or suburban residence, then computed the ratio before and after subtracting the hypothetical transportation-cost savings. The parameter described above from the Frey study was then multiplied by the change in this ratio.

It is worth mentioning that two alternative estimates of household location shifts were considered. One was a crude equilibrium model based on transportation costs with variable lot sizes, and an assumed ten-year adjustment time to the new equilibrium. The other was similar to the method finally adopted, but used instead a result by Bradford and Kelejian [2] on the relation between the proportion of households living in the city and a fiscal surplus variable. Neither was considered satisfactory on a priori grounds as the Frey paper, but the fact that both gave considerably larger household responses adds confidence to our belief that we have not wildly overestimated the magnitude of this decentralizing effect.

Secondary Impacts

In addition to those employers and households which respond directly to the incentives created by a transit project, there will be secondary rounds of response. Changes in job locations cause changes in the residential location of some workers [13], and in the unemployment status of others. Similarly, changes in the number of shifts in household location alter the geographical patterns of spending which influence location of "secondary" jobs dependent upon those spending flows. We dealt with these by means of a procedure described mathematically in the Appendix. It is based on a three-way breakdown of residential location (city, inner suburbs, and outer suburbs), and a four-way breakdown of job location which distinguishes separately the CBD, Workers filling new or relocated jobs are assumed to adjust their residential locations according to the actual distributions of residences by workplace in 1976, as measured by unpublished Census tabulation of journey-to-work data for the Cleveland area from the 1976-77 Annual Housing Survey. Assumptions regarding secondary-job locations, on the other hand, rely on a certain degree of judgment. The number of "indirect" and "in-

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*Both the household- and firm-responsive parameters could be overstated because the empirical results of Homer and Frey (ignore reverse causality through social effects). If jobs or households are dispersing in a metropolis area, the effect on tax bases is such as to increase the adjustment time to the new equilibrium. The influence of the sensitivity of tax differentials to intrametropolitan migration changes in the Cleveland area, however, suggested that this effect is not very large.
dued" jobs resulting from business and household spending associated with one primary job was taken to be 0.45 and 0.80, respectively, based on a study of the St. Louis area by Hirsch [9]; the implied overall job multiplier of 2.25 seems reasonably consistent with the literature on the subject. The location of such secondary jobs within the metropolitan area has not been studied. We therefore chose parameters intermediate between two extremes: (1) if secondary jobs resulting from business or household spending were created in the same location as that business or household, or (2) if the location distribution of secondary jobs were the same as that of all jobs, independent of the source of spending. The chosen parameters are given in the Appendix, as are the results of a sensitivity analysis using analytically these two extreme assumptions. The qualitative results do not appear to be overly sensitive to these secondary impact assumptions.

Because the Frey study estimated the total impact of taxes on intraregional migration, these secondary effects are presumably already included in the estimates derived from the study. We therefore invert the above procedure, in the case of household incentives, in order to find the primary shifts consistent with the estimated total shifts; the "induced" job relocations are then computed from these primary household shifts.

III. Simulation Results

Policy

The transit package considered is a scaled-down version of the Ten-Year Transit Develop

[12](1968, pp. 191–192) derives a multiplier of 3.0 for Wichita, Kansas in 1955, and the same figure is assumed by Knight (1977, p. 24) for the combined Cleveland-Northeast Ohio areawide Coordinating Agency (NOAA-

ment Program [24], recommended in 1974 by the Urban Transportation Task Force under the leadership of the Northeast Ohio Areawide Coordinating Agency (NOAA-

The full program included greatly expanded service on existing streets and rail lines, major extensions of the existing 12-mile rapid rail system, a downtown subway distributor, a downtown "people-mover," and a number of alterations to existing highways. Its total cost of over one billion dollars in 1973 prices makes this package an unlikely candidate for implementation, in view of the recent trends in the region. However, for many corri-

is the 1968 Ohio transport plan to serve the region and thereby increase the effective interce-

ators the consultants provided alternative plans for new busways or bus priority lanes on freeways, for which costs were lower and estimated benefit-cost ratios higher. By selecting a number of these radical alterna-

[13] The basic concept of the project is to provide a package which might provide perhaps one-half of the travel-time savings used to support the larger plan, so that the total investment cost of about $26.7 billion in 1977 prices. Its important elements are a $600-million loop subway for the CBD, and 37 miles of new exclusive grade-separated busways on four major corridors into the CBD at about $4 million per mile. For simplicity, we assumed the construc-

[14] We also assumed that the increases in existing service would take place gradually over the period 1981–1985. Rather than complicate the analysis by a year-by-year calculation for each effect, we approximated the effects by assuming that relocation incentives would begin at full strength in 1983.

[15] We also simplified the analysis of how much of the travel-time savings would accrue to the diversion of travelers to the recall packages. For example, the local transit survey taken in 1976.

[16] Since a larger share of the commuters would be expected to continue to use the existing packages, the recall packages would have a smaller impact than the recall packages. In contrast to the per cent of all transit trips which were CBD-oriented, according to a local travel survey taken in 1976. Travel-

[17] Demand studies have generally found that in-vehicle time is valued by commuters at one-third to one-half the wage rate, and walk-

0.80.

[18] For a clear explanation of this general proposition for the specific case of transportation improvements.

[19] Job Creation. Using the parameter pre-

[20] Increased CBD Accessibility. The cons-

[21] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[22] Job Creation. Using the parameter presented earlier of 30 jobs per million dollars in permanent annual operating cost, the $36 million estimated for annual operations implies 1,080 permanent new jobs in 1990, all of which were assumed to be located within the city. The direct stimulus is even larger in 1985 because of construction jobs.

[23] Increased CBD Accessibility. The cons-

[24] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[25] Job Creation. Using the parameter present-

[26] Increased CBD Accessibility. The cons-

[27] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[28] Job Creation. Using the parameter pre-

[29] Increased CBD Accessibility. The cons-

[30] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[31] Job Creation. Using the parameter present-

[32] Increased CBD Accessibility. The cons-

[33] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[34] Job Creation. Using the parameter pre-

[35] Increased CBD Accessibility. The cons-

[36] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[37] Job Creation. Using the parameter pre-

[38] Increased CBD Accessibility. The cons-

[39] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[40] Job Creation. Using the parameter pre-

[41] Increased CBD Accessibility. The cons-

[42] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[43] Job Creation. Using the parameter pre-

[44] Increased CBD Accessibility. The cons-

[45] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[46] Job Creation. Using the parameter pre-

[47] Increased CBD Accessibility. The cons-

[48] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.

[49] Job Creation. Using the parameter pre-

[50] Increased CBD Accessibility. The cons-

[51] The direct impacts of the tax system with respect to job creation, employer response to CBD accessibility, and household response to differential commuting costs were estimated for the years 1985 and 1990. The 1990 estimates, which contain the largest impacts, are described below.
ing and waiting time somewhat higher; we therefore valued all time savings at one-half the projected 1985 average manufacturing wage for the SMSA, or $4.15 per hour in 1977 prices. Using these assumptions, the transit package can be characterized as providing $29 million in annual cost savings on CBD trips. According to the earlier assumptions, this would cause the net outmigration of CBD jobs to fall by 580 jobs per year starting in 1983. This amounts to an increase of 4,250 downtown jobs by 1990 from the direct incentives of increased profits. We assumed one-half of these would be displaced from the inner (Cuyahoga County) suburbs, and one-half from the rest of the SMSA.

**Household Location Incentives.** Another way to characterize the assumed time savings of the transit package is by the saving per trip of various types. Using local information on the number and length of CBD trips, and using approximate distances from the various residential rings to the CBD, we arrived at the following estimates. The average time saving per CBD transit trip would be 8.5 minutes, one-fourth of which was assumed attributable to a 3-mile collection and distribution component regardless of trip origin. Based on average CBD-bound work-trip distances from city and suburban residential locations, we arrived at estimated time savings of 6.5 minutes for CBD transit trips from elsewhere in the city, and 13.5 minutes from the suburbs. Similarly, for auto trips to the CBD, the saving would be 1.7 minutes from the city and 3.7 minutes from the suburbs. It should be understood that these one-way time savings apply to trips in both directions.

This appears to favor the suburbs, but it

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**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>Direct Effect</th>
<th></th>
<th>Total Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jobs</td>
<td>Households</td>
<td>Population</td>
</tr>
<tr>
<td>Direct Job Creation</td>
<td>1,800</td>
<td>-440</td>
<td>+1,360</td>
</tr>
<tr>
<td>Increased CBD Accessibility (4,250 primary jobs in CBD)</td>
<td>-5630</td>
<td>-640</td>
<td>+1,610</td>
</tr>
<tr>
<td>Differentially Reduced Commuting Cost (990 total households in city)</td>
<td>-410</td>
<td>-900</td>
<td>-2,290</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>7,020</strong></td>
<td><strong>170</strong></td>
<td><strong>+400</strong></td>
</tr>
</tbody>
</table>

**Total Impacts**

The results of the simulation follow from the impacts computed above, with the secondary impacts computed as explained in the Appendix. Some results for Cleveland city are given in Table 1; further details are contained in the Appendix. They show the total effect to be pro-city for jobs, and practically neutral for households and population. The number of jobs in the city is substantially greater, and the number of households somewhat greater, than would be the case without the transit program. For neither jobs nor households is the effect anywhere near enough to eliminate the decline projected for the Base Case, but for jobs it is comparable to the effect found from simulating a job stimulus program of similar cost. Given the potential for error, however, the most important finding may well be that the opposing effects of improved accessibility to CBD and suburbs are indeed of comparable magnitude, and are therefore substantially offsetting.

**IV. Conclusions**

Whether or not the exact numbers derived here are accurate, a number of conclusions would appear to be supported by the analysis. First, easily-downsized systems do have offsetting effects, each substantial in magnitude, on the number of households within the city. The same is true, to a lesser extent, with respect to jobs. Even if those with financial interests at stake would permit it, those effects are too large to be ignored. Tools currently available do give us some idea of the magnitudes involved.

Second, because the negative effect on the city operates through residential location incentives, the net impact is considerably more favorable with respect to jobs than to households. Since these are primarily downtown jobs, it follows that the prime beneficiaries are likely to be owners of land in the central business district.

Third, the relatively stronger positive impact on jobs suggests that improving transit on radial corridors provides further impetus to the tendency of large cities to become daytime centers of activity. The kind of travel most facilitated by radial improvement is peak-period travel between suburbs and downtown, which has the effect of increasing the ratio of daytime to nighttime population.

Fourth, the balance of positive and negative effects on the city may be strongly dependent upon the details of the transit program. There is no reason why every system should result in the same net outcome as the one considered here. A transit program more tailored to the needs of downtown distribution, and less with radial lines to the suburbs, would have a more pro-city
impact on households and population. Furthermore, improving circulation within the city, as is the goal of many para-transit operations, probably results in fewer adverse effects on the city itself. However, little light is shed by this analysis on the relative merits of fixed guideway versus bus-on-highway systems for the radial corridors.

Finally, although highway projects have not been explicitly analyzed here, it is clear that a transit improvement is more pro-city than is a highway improvement providing comparable total travel-time savings. In the case of transit, the dispersive effect of lowering transportation cost, so well known to theoretical urban economists, is at least partially balanced by the fact that the cost reductions are predominately on a mode of transportation more frequently used by city than by suburban residents. The reverse is true of highway improvements: Not only are costs per mile lowered, but they are lowered most for those already using a mode well suited to the suburbs. Furthermore, because of the importance of trucking to many industries [18], highways are more likely than transit to provide cost advantages to suburban job locations.

These conclusions have been derived from a single simulation which can make no claim to universality. Much remains to be tested about the range of circumstances within which they are valid. They have, nevertheless, strong implications for transit policy in declining cities which appear worthy of careful consideration in individual cases.

Appendix

The method of computing secondary shifts in households and jobs caused by directly induced changes (relative to the Base Case) is summarized here. It is based on a set of vector and matrix equations in which the rows and columns represent the following geographical regions:

Jobs (Workplace Location)
1. CBD
2. Balance of central city
3. Balance of central county
4. Balance of SMSA

Other Variables (Residential Location)
1. Central city
2. Balance of central county
3. Balance of SMSA

Residential Location of Workers.
Any change in number of jobs at a given workplace location is assumed to be accompanied by changes in residential location in proportion to the distribution of workers in 1976. For the Cleveland SMSA, this distribution is described by the matrix $Q$ whose $i$th column gives the residential distribution of workers at workplace location $i$.

$$ Q = \begin{bmatrix}
0.60 & 0.15 & 0.10 & 0.08 \\
0.15 & 0.55 & 0.20 & 0.12 \\
0.20 & 0.25 & 0.60 & 0.30 \\
0.05 & 0.05 & 0.10 & 0.50
\end{bmatrix} $$

with alternate values for sensitivity analysis:

$$ Q_{25} = \begin{bmatrix}
0.00 & 0.00 & 0.00 & 0.00 \\
0.01 & 0.00 & 0.00 & 0.00 \\
0.00 & 0.00 & 0.00 & 0.00
\end{bmatrix} $$

$$ Q_{10} = \begin{bmatrix}
0.17 & 0.17 & 0.17 & 0.17 \\
0.25 & 0.25 & 0.25 & 0.25 \\
0.45 & 0.45 & 0.45 & 0.45 \\
0.13 & 0.13 & 0.13 & 0.13
\end{bmatrix} $$

The matrix $Q$ is in each case equal to the last three columns of $Q$.

Unemployment
A fraction $\delta$ of any change (relative to the base case) in employed workers living at residential location $i$, caused by shifts in job locations, is assumed to represent the employment of otherwise unemployed members of the labor force living at $i$. The remaining fraction $(1 - \delta)$ is assumed to represent net migration of labor force into residential ring $i$. Based on assumptions about proportions of jobs of various skill categories likely to be filled by previously unemployed workers, we chose

$$ \delta = 0.25 $$

Household location shifts in response to direct transportation incentives, on the other hand, are assumed to involve no unemployed members of the labor force.

Households, Population, and Income
Net migration of labor was assumed accompanied by migration of households and population, according to projections of the Base-Case ratios of households and of population to labor force. Those projections were based on actual data for the Cleveland SMSA from the Annual Housing Survey of 1976, and projected trends in these ratios for the United States by the Census Bureau. The U.S. household projections are the Census Bureau's Series B projection; the U.S. population projections are a mixture of 75% from Census Series III and 25% from Series II projections, this mixture being designed to approximate an assumed continuation of the total fertility rate of 1.8 which has characterized the last few years.

Migrating employed members of the labor force are assumed to have the average income of all employed workers in the SMSA; this figure is projected based on BLS projections of U.S. personal income per capita [19] and on extrapolation of the 1959-1974 trend in ratio of Cleveland SMSA to U.S. money income per capita (U.S. Bureau of the Census, City and County Data Book, 1977).

A change in status from unemployed to employed member of the labor force is assumed to raise the income of the worker involved from a level representing average unemployment compensation per unemployed worker in the SMSA, to a level representing average earnings for laborers in the SMSA (inflated to the appropriate years by the BLS projections of rise in real compensation per job). The former was estimated to be 14 percent of the latter.

These parameters are listed below.

Fraction of population in households: $a = 0.985$
Average household size: $\bar{N} = 2.600$ (1985) $2.505$ (1990)
Population per member of labor force: $\frac{P}{L} = \frac{2.600}{1.985} = 1.317$
\[ \beta = 1.901 \text{ (1985)} \]
\[ 1.862 \text{ (1990)} \]
Annual income per employed member of labor force (1997 dollars):
\[ y^p = 19,259 \text{ (1985)} \]
\[ 21,005 \text{ (1990)} \]
Change in annual income for formerly unemployed worker (1977 dollars):
\[ y^m = 9,990 \text{ (1985)} \]
\[ 11,520 \text{ (1990)} \]

Equations for Secondary Effects of Primary Job Shifts
In this case, location incentives on employers cause shifts in primary jobs which, in turn cause shifts in location of households and of secondary jobs.

Primary job shift (4-component column vector, by workplace location):

\[ \Delta J^f \text{ (given)} \]

Total job shift:
\[ \Delta J = (I + qQ + rR) \Delta J^f \]

Labor force (3-component column vector, by residential location):

Employed:
\[ \Delta L^e = \Delta J^e \]

Unemployed:
\[ \Delta L^u = -\alpha \Delta J^e \]

Total:
\[ \Delta L = \Delta L^e + \Delta L^u \]

Households (3-vector, by residential location):
\[ \Delta H = \alpha \gamma \Delta J \]

Note: \( I \) is the 4 \times 4 identity matrix.

Equations for Secondary Effects of Household Shifts
The sequence in this case is a directly induced shift of households (\( \Delta H^f \)) and associated employed workers (\( \Delta J^f = \Delta J^e + \alpha \gamma \Delta J \)), causing secondary job relocations (\( \Delta J^s = r \Delta J^f \)) and therefore a secondary round of household shifts (\( \Delta H^s = \Delta L^e + \Delta L^s \) and \( \Delta H^s = \alpha \Delta J \)). However, because the Frey study used to estimate household shifts does not hold secondary jobs constant, it is the entire household shift (\( \Delta H = \Delta H^f + \Delta H^s \)) which is given. We thus work backward to get the directly induced shift.

Total household shift (3-component vector, by residential location):
\[ \Delta H \text{ (given)} \]

Directly induced household shift:
\[ \Delta H^f = (I + rR)^{-1} \Delta J^f \]

Total job shift:
\[ \Delta J = (I + qQ + rR) \Delta J^f \]

Labor force (employed):
Employed:
\[ \Delta L^f = (I + qQ + rR) \Delta J^f \]

Unemployed:
\[ \Delta L^u = -\alpha \Delta J^f \]

Total:
\[ \Delta L = \Delta L^f + \Delta L^u \]

Note: \( I \) is the 3 \times 3 identity matrix.

Equations for Population and Income
The following apply to changes resulting from both forces identified in the previous two subsections:

Population:
\[ \Delta P = (1/\gamma) \Delta J \]

**Table A-1:** Cleveland Transit Improvement Package

**New Case**

<table>
<thead>
<tr>
<th>Year</th>
<th>Change</th>
<th>Impact</th>
<th>New Values</th>
<th>Change</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**After Policy Implementation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Change</th>
<th>Impact</th>
<th>New Values</th>
<th>Change</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LAND USE GOALS IN TRANSPORTATION POLICY

Aggregate Personal Income (1977 dollars):
\[ \Delta Y = y^p \Delta L - y^m \Delta L^m \]

**Detailed Results**

Table A-1 contains a more detailed description of the Base Case and the results of the simulation of the transit improvement package.

Table A-2 shows, in a form comparable to Table 1, the results obtained by using the extreme assumptions noted above for the matrices \( Q \) and \( R \). The results show that, as expected, the relative magnitudes of the centralizing and decentralizing effects do change, and therefore the net effect is subject to considerable uncertainty from this source. However, the qualitative conclusions derived in the text remain valid.
TABLE A.2: Impacts of Induced Traffic Package on City of Cleveland, 1990 (Alternate)

<table>
<thead>
<tr>
<th></th>
<th>Direct Traffic Generation</th>
<th>Direct Traffic Generation + Demand</th>
<th>Demands + Induced Traffic</th>
<th>Induced Traffic + Demand</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little America</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Independence</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

Notes:
- Little America: Location of the convention center.
- Rockside Entertainment & Convention Center: Location of the entertainment district.
- Independence: Location of the city's public transportation hub.

References:

EASTERN ECONOMIC JOURNAL
LAND USE GOALS IN TRANSPORTATION POLICY

42

LAND USE GOALS IN TRANSPORTATION POLICY

42

LAND USE GOALS IN TRANSPORTATION POLICY

42

LAND USE GOALS IN TRANSPORTATION POLICY

42