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URBAN STRUCTURE, TRIP GENERATION, AND POLLUTION: A REVIEW

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ABSTRACT

The primary purpose of this paper is to selectively review the literature with the intent of examining the relationship between the structure and form of the metropolitan area, its impact on the generation of trips, and the resulting distribution of air pollution within the central city. We suggest that an empirical analysis should be developed to explain how certain urban characteristics contribute to trip generation and thus to the environmental deterioration of the inner city. These characteristics include, but are not limited to, modal choice, the size of the CBD relative to the metropolitan area, work trip origins and destinations, and the structure of the highway network.

The growth and development of an urban area is a complex process determined by the economic and physical base of the city, the transportation network serving the city and the physical and social environment within the city. Over the years, urban planners, politicians and economists have sought to analyze and quantify the relationships within this tripartite feedback system. The importance of understanding these interrelationships is emphasized by the continuing decline of many of the older central cities within the United States and by the need to effectively plan the emerging cities. This paper serves to examine one part of the feedback system. Specifically, we will review the research concerning the effects

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of various urban structural parameters on the physical environment and the latters' subsequent interactive effect on city structure.

Since the mid-sixties, the quality of the environment has become a growing concern of the American public. Demands for cleaner air and water can no longer go unheeded by the urban politician. Damages to health, property values, vegetation and materials as a result of urban pollution can now be empirically documented [1–3]. In addition, migration to the suburbs and the decay of the central city as a viable economic area can be partly blamed on the condition of the social and physical environment. These negative externalities are an unfortunate byproduct of the large concentration of people and jobs that are necessary for an economically sound central city – a city which is capable of exploiting large economies of scale in the provision of public goods and services and providing accessability for employment, communications, cultural activities, and intercity transportation.

Historically, many variables have determined the environmental quality of this concentrated central city and its acceptability as a place to live and work. City size, income level and distribution, population and employment mix and location, and the availability of alternative modes of commutation have and will affect the relative use of transportation modes and the existence and location of stationary sources of pollution. These will, in turn, affect the spatial distribution and incidence of central city pollution. In the longer run, the quality of urban life will interact with residential and employment decisions. Future metropolitan areas will economically grow or stagnate depending to some degree upon the reaction of both firm and consumer to the quality of life. A better understanding of this relationship will enable both planner and economist to determine the most efficient allocation of resources for the urban area. At that time we will be better able to address such questions as:

1. Should density, per se, be encouraged for the central city and inner ring? Higher density areas are better able to support mass transit systems but also generate a greater number of intra-urban trips by automobile for both work and leisure. The subsequent congestion may further deteriorate the central city environment. Only after measuring the relative contributions of various structural characteristics on environmental quality may we state with confidence that a high density area is unambiguously beneficial from an environmental viewpoint.
2. Under what conditions would an inner city as opposed to a suburban corridor transit system be cost-effective in reducing central city pollution and promoting economic growth? Again, the answer may lie in the quantification of the affects of distribution of population and employment on central city pollution.
3. What affect may alternative energy and land uses have on central city pollution?

4. What wage, tax or amenity differentials may be necessary to encourage residential or commercial movement into a city?
5. How can city structure alone, affect the various air pollution control strategies?
6. What is the sensitivity of various income groups to environmental changes within the city?

Regardless of one's political and/or economic views on the role and future of cities, it is informative to consider the work that has been conducted on the interrelationships specified above and to delineate some of the gaps in knowledge that need to be filled.

There are three different types of models which may bear on the question of central city environmental deterioration. These include: models on modal choice, models projecting pollution emission, and models considering the allocation of land for housing and transportation. The assumptions of these models, their conclusions and their implications for policy concerning central city pollution will be discussed below.

MODAL CHOICE

Many urban planners and economists have recommended the development and support of intracity mass transit systems as essential to the maintenance and generation of growth within the urban core. By providing easy accessibility between home and workplace, both commercial and residential development would be fostered. The coexistence, and strong interdependence of a highly developed central business district (CBD) and mass transit system can be observed in many urban areas. The utilization of mass transit has also been regarded as a panacea for the continued environmental deterioration of the central city. The general belief is that mass transit, as a substitute for auto use, would reduce the total automobile miles traveled and consequently the ambient pollution levels. This need for a reduction of auto travel in many urban areas is obvious. Of the various pollutants emitted into the air in 1970, transportation was the source of 75 per cent of all carbon monoxide emissions, 56 per cent of the hydrocarbons, and 51 per cent of the nitrous oxides [3].

The increased environmental damage from mobile sources prompted legislation in 1970 requiring Implementation Plans for the reduction of air pollution within designated cities. In addition, the legislation promulgated emission standards which were to be met by automobiles at a future date. Unfortunately, continued increases in car ownership, longer work trips, increased per capita miles traveled, and mounting disdain for mass transit, has minimized the effectiveness of the emission standard strategy. Some researchers have already seriously questioned the cost-effectiveness of the mandatory auto emissions standard policy and have suggested other control methods for metropolitan areas [4, 5]. These include carpooling, priority bus lanes, two-car strategies, gasoline taxes, parking bans, staggered work hours, and finally, continued development of mass transit systems. The latter has come to represent one means of easing both the economic and environmental dilemmas common to many central cities and threatening others.

The strategy employed to increase mass transit usage through inducing modal switch may have both short and long run effects. It has been shown that the price elasticity of demand for mass transit is low, ranging from about .10 to about .35. The quality (time) elasticities have been shown to be somewhat higher, ranging from .35 to .85 [6, 7]. In the short run, however, changing the price (out of pocket or time costs) of auto travel creates an immediate affect on the chosen bundle (if auto chosen). Changing transit service requires time for the information concerning the change to be received, creating smaller short run increases in transit demand. Thus, it may be preferable to alter the price of auto travel to induce rapid modal shifts.

In the longer run, these two policies, may have different consequences for city form. Goldstein and Moses have considered the affect of changing auto prices on a multi-nuclear SMSA [8]. Assuming the individual has been minimizing travel costs, increasing auto travel increases total travel costs to those choosing this mode. (Otherwise, a lower cost mode would have been chosen.) Higher total travel costs create a greater desire to live closer to work locations, making the CBD less and the other cities more desirable as work locations. Households and industry may further decentralize exacerbating central city problems.

Changing the quality of service to the CBD has the opposite affect. The higher quality service makes the area served more desirable for residential location, expanding the labor pool and making the CBD a more attractive business location. The outward migration from the central city may be reduced. Therefore, alternative modal choice policies can affect the subsequent form of the city. We will argue below that these structural changes influence subsequent environmental quality.

The use (or non-use) or mass transit, per se, may be only one of a series of important determinants of urban environmental quality, however, In New York City, Boston and Newark, three cities among the highest in mass transit utilization, significant CBD pollution from mobile sources still exists [9]. Even among cities of equal transit use and population, there may be wide variations in the quality of air near the CBD. This suggests three areas of further study: first, the tradeoff of CBD development and high mass transit use *versus* the potential for higher pollution concentration; second, the affects of mass transit policy on long run urban structure; and third, the influence of variables besides modal choice on the distribution of pollution.

THE POLLUTION EMISSIONS MODELS

Although their aims were different, two recent studies have attempted to generate models predicting central city pollution given various parameters of the urban area. Harrison estimates the various costs and benefits to different income groups resulting from alternative mobile source pollution control strategies [4]. In order to estimate the total vehicle miles traveled (VMT) for a household in a given income class and for a given number of cars owned, Harrison utilizes data that generalize VMT for households, regardless of geographic area. He states that, "geographic differences in miles of travel are probably small, after the household's income, the number of cars owned, and the cars' age are accounted for." However, between cities, differences in VMT and the number of autos traveling past a given point in the city can generate significantly different distributions of pollution. Specifically, two structural parameters, population and employment density of the city and suburb, are important determinants of the resulting central city pollution. By comparing two cities with the same characteristics except for population density, different pollution levels may be observed. The difference is derived from the realization that greater density implies greater trip demand by the public within a given area. An increase in trip generation, coupled with a probable reduction in average speed, will result in more emissions of carbon monoxide and hydrocarbons. Also, a larger number of people starting their automobile engines in a given area will have far different effects than will the same number of people merely driving through the same area. Emissions from cold starts are generally six times that of "pass through" emissions. Thus, we need to consider not only VMT and therefore total emissions projected, but the distribution of emissions or a "pollution gradient" for the urban area.

Zerbe and Croke have developed a model which comes closest to answering some of the questions raised above [10]. Using detailed transportation data for the Chicago metropolitan area, they evaluate various policies designed to reduce urban mobile source pollution. After dividing the region into a number of square grids, they apply data such as average VMT, speed and number of cold starts from each grid, and an auto profile including deterioration and speed adjustment factors to determine the emissions generated in each grid. Part of their work analyzes the effectiveness of fare changes, parking bans, time differences and gasoline taxes in promoting mass transit, by using previously estimated modal choice equations. Thus, they are able to estimate the decrease in auto use as a function of distance from the CBD. There appears to be two deficiencies in their otherwise comprehensive analysis. First, as they point out, in order to estimate the ultimate effect of these modal switches on emissions, they must assume an arbitrary number of miles that each car traveling to the CBD must drive within the CBD itself. This is dependent on the particular geographic form and highway structure of Chicago. Generalized results, therefore, are difficult to generate. Second, there is no consideration of possible changes in city form. For example, changes in origins and destinations over time cannot be evaluated unless one assumes that the modal choice proportion is independent of changes in population density and work location. However, people moving into high density areas will tend to have a smaller average number of cars/person and may intensively support the existing mass transit system. Because of this density increase, more non-work trips within the given area may be generated and more people will suffer the damages of the existing pass-through emissions. Thus, the effects of density on pollution levels and damage deserve special study especially when considering longer run phenomena. While Zerbe and Croke's work is certainly a considerable addition to the analysis of economics and environmental control, it leaves unanswered problems such as the advisability of high density areas, suburban highway development and various land use zoning techniques for improving environmental quality.

TRANSPORTATION AND LAND USE

The pattern of land use in a city is largely determined by the structure of the transportation system within the urban area. Since the relative mix of land use activities (residential, commercial, transportation) will determine subsequent air quality levels [11], the type and size of the transportation system and its interaction with the pattern of development must be incorporated into any analysis of expected long run pollution levels.

In their seminal work, Solow and Vickrey consider the interaction of transportation and land use [12]. They conclude that, under certain restrictive assumptions, "the market value of land may be a very poor guide to land use decisions and lead to over-allocation of land to transportation, especially near the center." The potential impact of this overallocation on pollution levels may be severe. Since travel demand is a function of available highway services, an overallocation may call forth trip making activity which is in excess of the travel demand generated by an optimal allocation of land. This higher trip making activity will create increased levels of pollution from mobil sources. Thus, the equilibrium implied by a given highway system may be also suboptimal when pollution levels are concerned.

Highway capacity in excess of the optimal can further affect city form, and thus pollution levels, if it alters the distribution of population and thus the city's density gradient. Classical land use models show that increasing the ease of mobility of an individual by lowering the total cost of transportation (time and out-of-pocket costs), will cause the individual to substitute transportation for other goods [13–15]. In this case, the individual moves further from the CBD, flattening the density gradient. Haring, Slobko and Chapman conclude that an increase in transport capacity leads to a change in the rent gradient, making it

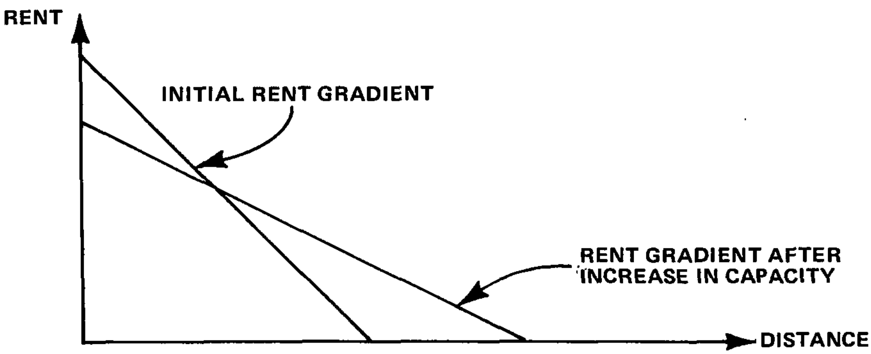

Figure 1.

flatter [16]. The result is less of a differential between CBD rent and boundary rent, with the boundary moving out (see Figure 1). The long run affects of this change on the Macro (city wide) level is a redistribution of population and a density gradient change.

The change of the density gradient as a result of the increased highway capacity, can affect the level of pollution in two ways. First, the concentration of stationary pollution sources, on average, should be lowered, lowering the ambient levels at any measurement point. The magnitude of this change will depend on the land use pattern implied by the new density gradient. Second, the pattern and distribution of mobile sources will be altered. As pointed out above, cold starts are a major factor in pollution levels attributed to auto usage. A less dense city implies a lower concentration of "cold-starts," an increase in miles traveled and the potential for greater auto use (a modal switch). On net, there should be a lowering of absolute pollution levels, and a flattening of the pollution gradient.

Unfortunately, the understanding and modelling of the interaction of over-allocation of land for transportation and urban form, has hardly begun. In "Transportation and Urban Land Values: A Review of the Theoretical Literature," Roger Alcaly observed that, "what is needed . . . is a model of the urban economy in which the provision of transportation services is explained rather than taken as a given datum." [17] However, accomplishing this end requires specification of the "direction of causality in the relationship between transport improvements and urban land values," which is something lacking in most of the literature (Alcaly) reviewed. Without this specification policy statements cannot include the full measurement and impact of social costs.

The construction or improvement of a highway produces a change in the available public service package for the impacted area. The alteration of the bundle may have either positive or negative affects on property value and the subsequent utility of residents. Some research into the affect of highway improvements on property values has been undertaken.

Herbert Mohring, determined that highway construction has a two-step affect on the city [18]. First, if the construction reduces transportation costs by lowering time in travel the rent gradient will pivot with the city boundary intact. Concurrently lower rents imply less intensive use of land, so that rent at every location falls causing an outward shift of the entire rent curve. The result is similar to that portrayed in Figure 1. Depending on the elasticity of demand for land, density will change. As described above, the new land use pattern will alter the level and distribution of pollution.

John Langley found that highway construction reduces the desirability of residential land located nearby the highway, but increases land value for commercial or industrial use [19]. This was based on his findings that "land located near highway interchanges may increase many times in value due to its attractiveness (easy accessibility) for purposes of industrial or commercial use." He estimated a difference in residential land values between areas near ("abutting") a highway to be $1,650 less than further away ("non-impacted") areas. Langley's findings imply a change in land use mix while Mohring's [18] imply a change in land use intensity. Both imply a change in the distribution of air quality from the pre-highway construction allocation of land, as the mix of mobile and stationary pollution sources is changed.

The allocation of land for various uses will affect areas outside the directly impacted zone through changes in mode and highway network usage. As John Meyer and Mahlon Straszheim point out "even in simple transport systems, additions to the network introduce dependences among projects [20]. Adding new links can significantly change entire connections and the resulting pattern of network usage and performance. Often a new link in a transport system will substantially affect the use mode of another link or facility not only parallel or complementary to the new link but sometimes considerably removed from and not directly related to it." The transportation improvement in one zone can affect pollution levels in the surrounding urban areas because of the linkages in the highway system. For example, if the average travel speed of connecting arteries is reduced, autos will emit more CO and HC and less NOx per mile [21]. Some scientists now believe that NOx emissions may be relatively more harmful and that future increases in the use of diesel engines will exacerbate the problem. Thus, the need for higher or lower speeds and the relative damages of pollutants must be evaluated within each urban area.

Planners must understand the implication of the modal choice and route assignment decision and the resultant feedback on land use and the environment. Decisions should be made in view of both long and short run ramifications, since the results of a policy may be different over time. As we pointed out in the modal choice section above, the type of modal choice policy implemented will affect urban form. Thus, even though amount and usage of mass transit might not directly explain pollution levels, the affect on urban form of past transit policies may help explain present levels of pollution in a city, while future transit policies help explain future pollution levels. In addition, urban planners must incorporate into their long run planning the interaction of city form, highway structure and choice of mode on pollution levels. What appears to be optimal for society as far as one function is concerned (e.g., higher density) may have a negative impact on environmental quality through its relationship with the other functions. Until a simultaneous system is developed, the ramifications of a transportation and land use policy on long run pollution levels, will not be known.

ENVIRONMENTAL QUALITY

So far we have looked at only one side of the interaction of structure and environment. We now review some of the research concerning the affect of the physical environment on various urban structural parameters.

In the last few years a number of studies have attempted to estimate the affect of certain pollutants on urban property values. In a cross-sectional regression of 167 predominately urban census tracts of the St. Louis SMSA, Ridker and Henning [2] found a statistically significant negative relationship between the annual geometric mean sulphation rate (a common measure of sulphurous pollution) and owner-occupied residential property value. They concluded that if the sulphation level to which any single family dwelling unit is exposed were to drop by 0.25 mg of $SO_3/100\ cm^2/day$, the value of that property could be expected to rise by at least $83 but most likely closer to $285.

Anderson and Crocker [1], using the three metropolitan areas of Washington, D. C., Kansas City and St. Louis also examined this question of air pollution and residential property values. In these cities, physically and biologically harmful concentrations of suspended particulates and sulphur oxides were known to be present. Results from four different types of regressions show that in all cases the coefficients of at least one of the pollution variables was negative and statistically significant. These two studies suggest that changes observed in the housing market may partially capture the effects of environmental damages. Depending on the relative costs of intra- and inter-urban migration, these changes in property values (and subsequently, in density) may either be redistributed throughout an urban area of may result in an absolute decline in the total value of land and housing (and in total population) for the area. Polinsky and Shavell explore the ramifications of the "openness" of a city on the changes in property values, and determine when these changes can be utilized as a "willingness to pay" for pollution abatement [22]. Unfortunately, these property values estimates are of little help in calculating the damages from mobile source pollution. Transportation only accounted for 3 per cent of all particulate pollution and 3 per cent of the sulphur oxide pollution in 1970 [23]. Estimates of damages from carbon monoxide hydrocarbons and oxidants, the major emissions from automobiles, are extremely difficult to determine. The

Environmental Protection Agency has estimated that transportation sources produced approximately $1.1 billion in damages in 1970 [3]. This estimate would include damages to vegetation, materials, aesthetics, property values and health. Harrison writes, "clinical and epidemiological evidence on the health effects of CO concentration provides considerable basis for public concern [4]. There is considerable evidence that high levels of CO impair the heart and circulatory system and increase the risk of heart attack for persons with cardio-vascular diseases. Reactions dulled by CO concentrations may also be a contributing cause of highway injuries and deaths. In addition, high CO concentrations may be responsible for headaches and other minor ailments afflicting a much larger number of people." The relative impact of transportation related pollution may be exacerbated by its high incidence in urban areas, especially in densely populated zones inhabited by lower income groups [24].

In a more theoretical model, Fisch attempts to simulate the affects of air pollution on urban rent and population density functions [25]. He compares the present legal situation where the pollution recipient (the resident) bears the cost of pollution damage with scenarios where either the producer bears the cost or emission controls completely abate mobile source pollution. The results show that as long as environmental degardation is a source of disutility for the resident, the present legal situations will produce a lower average density and rent function in the city.

Using a similar model, Robson evaluates the impact of mobile source pollution on residential location decisions [26, 27]. He finds that the locational pattern under final equilibrium is too dispersed, and produces cities that are too large, relative to the optimum city structure.

Obviously, there is a need for further research on the affects of environmental quality on residential decision-making and urban structure. We believe that by reviewing some of the past work and depicting additional areas of concern, this paper serves as a guide for this research. When the interactions described above are fully understood, the allocation of resources within the urban sector will be improved and long run urban planning will become more effective in dealing with environmental questions.

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