Effects of Parking Provision on Automobile Use in Cities

Inferring Causality

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Many cities include minimum parking requirements in their zoning codes and provide ample parking for public use. However, parking is costly to provide and encourages automobile use, according to many site-specific studies. At the city scale, higher automobile use is linked to traffic congestion, environmental degradation, and negative health and safety impacts, but there is a lack of compelling, consolidated evidence that large-scale parking increases cause automobile use to rise. In this study, the Bradford Hill criteria, adopted from the field of epidemiology, were applied to determine whether increases in parking should be considered a likely cause of citywide increases in automobile use. Prior research and original data from nine U.S. cities dating to 1960 were relied on. It was found that an increase in parking provision from 0.1 to 0.5 parking space per person was associated with an increase in automobile mode share of roughly 30 percentage points. It was also demonstrated that a majority of the Bradford Hill criteria could be satisfied by using the available data; this finding offers compelling evidence that parking provision is a cause of citywide automobile use. Given the costs associated with parking and its apparent effects on automobile use, these findings warrant policies to restrict and reduce parking capacity in cities.

Most municipalities in the United States set minimum parking requirements (*1*). These policies assume that the appropriate supply of parking can be determined by estimating the potential demand and aiming to meet that demand. This view is reinforced through the Institute of Transportation Engineers' *Parking Generation* (*2*) and similar guides. However, it typically fails to account for the complex relationships between parking supply and demand. This relationship is problematic for many well-documented reasons. Parking is expensive to provide, thereby driving up construction and rental prices; it consumes large amounts of space, thereby limiting development potential; and it often encourages driving (*3*).

This last point—the influence of parking on automobile use—is the primary focus of this study. There is a substantial body of literature describing the many ways that the price and availability of parking influence automobile use and travel behavior. For example, the price of parking at the workplace influences whether employees choose to drive alone (*4–6*). It also influences where and when people choose to travel for discretionary trips and where they choose to park once they arrive (*7*). Guaranteed parking at home influences whether commuters drive to work or take transit (*8, 9*).

These studies suggest that minimum parking requirements, public parking provision, and other mechanisms that push the citywide parking supply upward could potentially cause citywide automobile use to increase over time. Prior research has shown that parking supply and automobile use are correlated across different cities (*10, 11*) and that automobile use increased considerably in cities where parking increased (*12, 13*).

The primary question in this study, therefore, is one of causality: do citywide changes in parking actually cause automobile use to increase or are minimum parking requirements an appropriate response to already rising automobile use? The purpose of this study is to consolidate the available knowledge, contribute original data, and apply a robust, scientifically accepted framework for inferring whether causality exists. In addition to prior research, data related to parking provision and automobile use for nine U.S. cities in 1960, 1980, and 2000 are relied on; these data allow the tracking and analysis of changes over time.

Causality has been the subject of numerous prior travel behavior studies, particularly those aiming to parse out the effects of residential self-selection. The most common approaches, in lieu of controlled experimental design, include direct questioning through surveys, statistical models that control for residential location choices, longitudinal studies, or some combination of each (*14–16*).

Several studies use household travel surveys to control for residential location, which the authors of these studies consider a treatment effect that explains attitudinal differences (*17–19*). Several other studies rely on a comprehensive travel survey administered across eight neighborhoods in northern California in 2003, which includes information about attitudinal differences, how recently a resident moved, and his or her current location; these data allow the authors to conduct cross-sectional and quasi-longitudinal analyses (*14, 15, 20*). Similarly, Joh et al. rely on the South Bay Travel Survey, administered between 2005 and 2007, controlling for attitudes about walking (*21*).

Since the current study involves understanding changes in parking supply and travel behavior at the city scale over multiple decades, the options for parsing out causality are especially limited. Comprehensive travel surveys and detailed location data are not available. The most consistent source of travel data is from journey-to-work surveys administered by the U.S. Census Bureau each decade dating

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back to 1960. Since no reliable database of historical parking supply exists, the authors' own estimates are developed by using available aerial photographs. The effort required to develop these estimates limits the potential sample size considerably. These limitations rule out many common approaches including controlled experiments, direct questioning, and statistical modeling.

Instead, a widely accepted general theory of causality, adopted from the field of epidemiology, is relied on; it is commonly referred to as the Bradford Hill criteria (*22–25*). The nine criteria, first presented in a 1965 speech by Austin Bradford Hill, a professor emeritus at the University of London, are intended for inferring causality when an association already exists. They are not meant to serve as a checklist or set of rules but instead to answer the question, What aspects of an association should be especially considered before it is decided that the most likely interpretation is causality (*22*)? According to Bradford Hill, "the decisive question is whether the frequency of the undesirable event B will be influenced by a change in the environmental feature A" (*22*). The nine criteria are strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, and analogy.

In the current case, an environmental feature A refers to parking supply and the event B refers to high levels of automobile use, which many policy makers consider undesirable because of a range of environmental, social, and economic consequences, including traffic congestion, traffic deaths, and pollution. This approach allows the research to overcome an inherent challenge, which is that there are many potential explanatory variables (e.g., changes in transit service quality) and a lack of reliable data for many of those variables. By approaching the question of parking supply and automobile use in this way, other factors cannot be discredited, but a reasonably definitive answer can be gained regarding the potential citywide impacts of parking on travel behavior and evidence-based policy recommendations can be made to achieve long-term transportation-related goals.

By demonstrating that parking contributes to rising automobile use, this research calls into question the underlying justification for minimum parking requirements in urban areas. These requirements, like many transportation policies, employ a predict-and-provide approach through which planners and designers provide infrastructure based on estimates of future demand. If the hypothesis that parking causes driving is true, however, parking has an induced demand effect (*26*), which should be taken into account and managed accordingly through mechanisms like maximum parking allowances and pricing.

DATA AND METHODOLOGY

For this study, the Bradford Hill criteria are reviewed and used to gain a better understanding of whether parking provision is a likely cause of automobile use in American cities. The original data and analysis are relied on as well as additional knowledge gained from earlier studies.

The current study begins in 1960, when the earliest, most consistent data are available. Three specific points in time are considered—1960, 1980, and 2000—and the two time periods those dates represent (before and after 1980).

City Selection

Some historical data used in this study are only available at the city scale; this drawback prevents the conduct of more fine-grained analyses of individual neighborhoods. Therefore, only cities that are reasonably similar in size and form are included. Nine medium-sized U.S. cities were selected—building on earlier studies (*10, 12, 13*)—from a database of more than 100 cities based primarily on population size and changes in automobile use between 1960 and 2000. Their population size ranges from approximately 100,000 to 300,000 and none of the cities experienced marked population growth over the study period; this feature indicated that they were largely built up by 1960. The cities represent a full range of automobile use, including some cities with exceptionally low automobile mode shares. Connecticut and Massachusetts are heavily represented because of the availability of historical aerial photographs from university libraries in each state.

Parking Supply Data

The main source of original data for this study—and an important contribution of this work—pertains to parking provision as early as the 1950s and as recently as 2009. To the authors' knowledge, this is the most comprehensive set of historical, citywide parking supply data that exists.

To estimate available parking, high-resolution aerial photographs were compiled for the following cities and years:

- Albany, New York: 1952, 1994, and 2007;
- Arlington, Virginia: 1957, 1985, and 2009;
- Berkeley, California: 1958, 1985, and 2009;
- Cambridge, Massachusetts: 1952, 1985, and 2009;
- Hartford, Connecticut: 1957, 1985, and 2009;
- Lowell, Massachusetts: 1952, 1985, and 2005;
- New Haven, Connecticut: 1951, 1985, and 2008;
- Silver Spring, Maryland: 1964, 1988, and 2009; and
- Somerville, Massachusetts: 1955, 1978, and 2008.

Some researchers have estimated parking supply by evaluating individual sites with field data (*27, 28*) or online tools like Google Streets and Bing Maps (*29*). Unfortunately, these methods are not available for estimating historical parking supply, nor would they permit the desired scale of analysis within the study's resource constraints.

Land used for off-street parking was identified in geographic information systems by visual inspection using methods outlined by McCahill and Garrick (*13*) and similar to those described by Davis et al. (*30*). This land includes any visible off-street parking facility with more than three spaces, including multilevel parking structures. For older aerial photographs, which are generally of lower quality, a minimum and a maximum area of parking were determined for each city and the midpoint of that range is reported.

To estimate the total number of parking spaces, the total area was divided by 350 ft^2 (32.5 m^2)—the average area per parking space based on a sample of 100 lots. The footprint of parking structures was multiplied by four to estimate their rough capacity. Values for 1960, 1980, and 2000 were estimated from values in known years by using linear interpolation or projection.

Census Data

The U.S. census reports place-based journey-to-work flows by travel mode as early as 1960. These data are reported in printed journey-to-work records from 1960 to 1980 and as part of the Census Transportation Planning Package from 1990 to the present. They allow the calculation of the number of residents and employees commuting to or from each city and the automobile mode share for each year of interest. They also allow the isolation of local commute trips—those that begin and end within a city. Data on workers and local trips are not available for Lowell, Massachusetts, in 1960 or for Silver Spring, Maryland, between 1960 and 1980.

By focusing only on the commuting behavior of residents, a more robust data set was also gained that reflects all of the cities—including Lowell and Silver Spring—dating back to 1960. These data are available at the census tract level from the National Historical Geographic Information System (*31*).

APPLYING BRADFORD HILL CRITERIA

Bradford Hill and other researchers note that before the nine criteria can be employed, a clear association between the treatment and the outcome must first be established (*22, 23*). As shown in Figure 1, the relationship between parking provision (parking spaces per resident and employee) and automobile use (automobile mode share for workers) was considered for each year and a clear, consistent association was observed ($R^2 = .79$).

Strength

Strength of association is the first of nine criteria identified by Bradford Hill. The criterion states that a large response in relation to treatment is a compelling indication of causality. As an example, Bradford Hill cites the fact that cigarette smokers are 9 to 10 times more likely to die from lung cancer than nonsmokers.

When the treatment is a simple binary—e.g., smokers versus nonsmokers—it is helpful to think of strength in terms of relative risk. Courts, for example, have found that a relative risk of 2.0—meaning that the risk is twice as high for a treatment group—indicates that an agent is more likely than not to have caused a disease but that more than one study is needed. Some scholars recommend a relative risk of 3.0 (*23*). Bradford Hill is careful to note, however, that one "must not be too ready to dismiss a cause-and-effect hypothesis merely on the grounds that the observed association appears to be slight" (*22*).

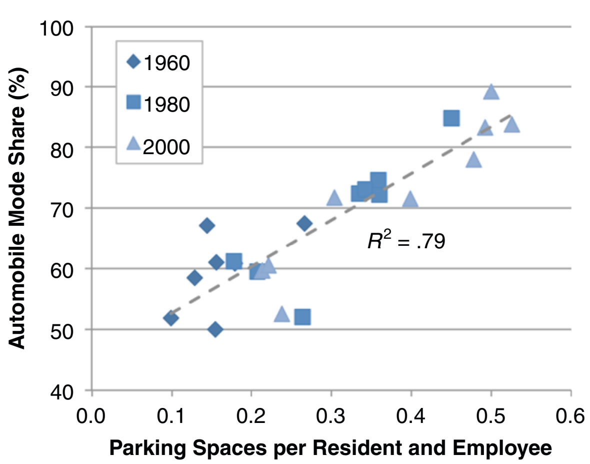

FIGURE 1 Parking provision versus automobile use for those who live or work in a city, 1960–2000 (data not available for Lowell in 1960 or Silver Spring in 1960 and 1980).

For this study, the association is considered to be strong if the slope of the curve in Figure 1 is large; this result indicates that changes in parking provision are associated with large changes in automobile use. The slope is .77 (p-value < .00), which indicates that a change of 0.1 parking space per person corresponds with a difference in automobile mode share of 7.7%. If cities with 0.2 parking space per person are considered as the control group and those with 0.5 parking space per person as the treatment group, the expected rates of automobile use are 60% and 83%, respectively—a relative risk of 1.4. Compared with epidemiological risk, this finding is somewhat low, but it is still consequential. In terms of urban automobile use and its related impacts, this relative risk is substantial.

Consistency

Consistency refers to whether an association has been observed repeatedly by different individuals, in different situations, and at different points in time.

As shown in Figure 1, the relationship between parking provision and automobile use has remained fairly consistent over a 40-year period from 1960 to 2000 for the cities in this study, and, if anything, that relationship has grown stronger. Few other studies look explicitly at the relationship between parking supply and automobile use, which makes it somewhat challenging to ensure consistency. Existing studies, however, validate the general idea that parking availability and automobile use are positively associated.

One recent study modeled the relationship between parking availability and automobile mode share at the census tract level in New York City (*8*); the results revealed that commuters to Manhattan's core are far more likely to travel by private automobile when there are more off-street parking spaces available per dwelling unit at their home location. An earlier, related study reached similar conclusions by comparing two New York City neighborhoods (*9*). Two studies of New York City also found that parking availability at home is positively associated with automobile ownership, which serves as a proxy for automobile use (*29*) and with automobile use directly (*32*). A separate study of automobile ownership in New York City found that a 10% increase in parking requirements is associated with a 5% increase in vehicles per square mile and a 4% increase in vehicles per person (*33*).

Kuzmyak et al. provide data from a 1997 survey of 17 U.S. cities, which show that the share of commuters traveling by single-occupancy vehicle increases as the number of spaces per employee increases (*11*). Supplemental data from one study of urban centers in New England (*34*) show a similar relationship between parking ratios—the number of parking spaces per unit area of building space—and automobile mode share (*35*).

International examples also validate this association. In Edinburgh, Scotland, one study found that automobile use was considerably lower within a limited parking zone than outside the zone and that a 1.5-mi (2.5-km) expansion of that zone could reduce automobile use by 21% for commute trips (*36*). Stated-preference surveys in Haifa, Israel, show that reductions in parking availability could make 23% to 45% of workers and 16% to 25% of nonworkers change modes, depending on how long parking search times increased (*7*).

Finally, numerous studies show that parking price—which is different from availability, but often related—also affects automobile use (*4–6, 11, 37–39*).

Specificity

Specificity refers primarily to instances in which the treatment effect is the only clear explanation for an outcome. As Woodside and Davis explain, "The crux of the specificity consideration is that causality is likely if a very specific population at a specific site develops a disease with no other likely explanation" (*23*).

One study in particular allows consideration of the issue of parking supply and automobile use through this lens. Weinberger et al. studied two specific neighborhoods in New York City—Jackson Heights in Queens and Park Slope in Brooklyn—to understand how parking availability at home influences individuals' decision to drive to work (*9*). The authors summarize their findings as follows:

> Indicators such as income, car ownership, density, government employment, and the difference between drive and transit times to the central business district (CBD) predict a higher share of auto commuting by Park Slope residents. Yet Jackson Heights residents are 45% more likely to drive to work in the Manhattan CBD and 28% more likely to commute by car in general. (*9*, p. 1)

They attribute this unlikely outcome to the fact that Jackson Heights has considerably more off-street parking. Specifically, residents are more than 2.5 times more likely to have access to off-street parking and more than 6 times as likely to have an on-site, private parking space. The authors conclude that guaranteed parking at home is the only clear factor explaining the relatively high rates of automobile use in that neighborhood.

Temporality

Temporality refers to the sequence of events governing an association and requires that a treatment must come before the outcome. This criterion is particularly difficult to test in the current case, given the broad time scale of the analysis and the complex interactions among factors. For example, although parking provision may contribute to rising levels of automobile use, it is also likely that, conversely, trends in automobile use affect parking policy and thus parking provision.

To test this theory, it is assumed that if one factor precedes another, it should be possible to predict the latter by looking at prior changes in the former. As an analogy, an individual's smoking habit can predict whether he or she will later develop lung cancer, but instances of lung cancer cannot necessarily predict whether somebody will take up smoking.

As shown in Figure 2, increases in the number of parking spaces per resident between 1960 and 1980 are directly correlated with increases in resident automobile use in the following two decades ($R^2 = .86$). However, changes in automobile use before 1980 are a much weaker predictor of parking increases after 1980 ($R^2 = .25$), as shown in Figure 3.

These findings are compelling evidence that even though the relationship between parking and driving is complex, parking provision appears to be the primary leading factor. Using the same analogy as the earlier one, this statement is like saying that even though somebody might begin smoking after developing lung cancer (possibly because the risk of developing cancer no longer exists), smoking is still the primary leading factor of lung cancer.

Biological Gradient

The biological gradient criterion states that a clear dose–response curve is strong evidence of causality. Bradford Hill points again to the case of lung cancer in smokers, which follows a linear relationship. A lower death rate among the heaviest smokers would be problematic, he suggests, but not necessarily evidence against causality.

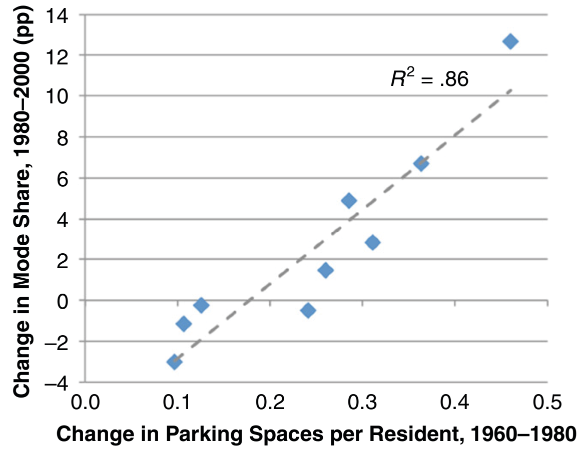

FIGURE 2 Change in parking provision (1960–1980) versus change in automobile use by residents (1980–2000) (pp = percentage points).

For this study, reference is made again to Figure 1, which shows that there is a clear, linear relationship between parking provision and automobile use. For those cities with the largest supplies of parking, rates of automobile use are considerably higher and the relationship is exceptionally strong in this higher range. In the most extreme cases, where there is more than 0.4 space per person, more than 75% of commuters travel by automobile.

Dose–response curves in conventional epidemiological studies often follow an S-shape curve or some other nonlinear form (*23*). Although the current data show a linear relationship, some curvature outside the range of the data is expected. Because automobile mode share cannot exceed 100%, this curve is expected to level off as parking increases and mode share approaches its maximum.

Data from two previous studies that consider town and city centers, reproduced in Figure 4, validate this concept (*34, 35*). As the number of parking spaces per 1,000 ft^2 (92.9 m^2) of building area increases, the automobile mode share also increases but levels

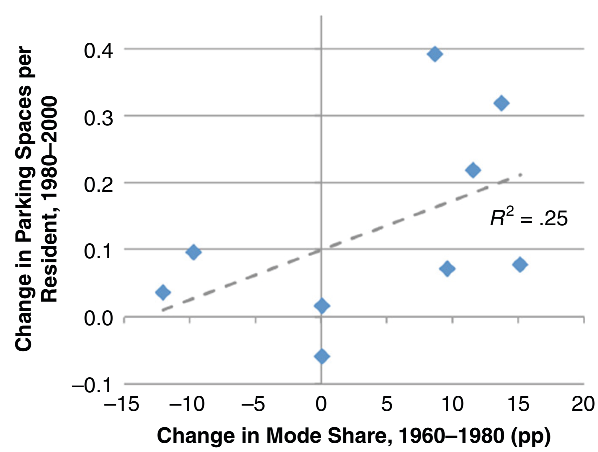

FIGURE 3 Change in automobile use by residents (1960–1980) versus change in parking provision (1980–2000).

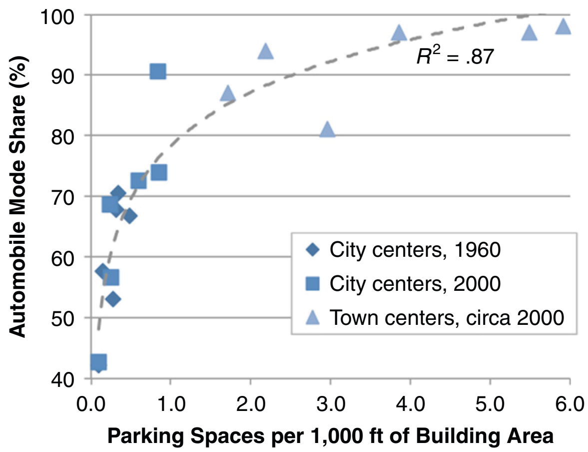

FIGURE 4 Parking provision versus automobile use for city and town centers (*34, 35*).

off as it approaches 100%. The regression line shown in Figure 4 represents the relationship between automobile use and the natural log of parking provision ($R^2 = .87$).

Plausibility and Coherence

Bradford Hill identifies plausibility and coherence as two separate criteria. In epidemiological studies, plausibility suggests that there is a reasonable biological explanation for a particular treatment to cause a particular outcome (e.g., a mechanism by which smoking could cause lung cancer). In contrast, coherence suggests that a theory of causality should not conflict with general knowledge about the nature of a relationship. As Woodside and Davis explain (*23*), "The difference between coherence and plausibility would seem, in part, to be one of semantics"—one suggests that evidence supports the theory and the other suggests that the evidence does not conflict. Therefore, the plausibility and coherence criteria were considered together.

In fact, general knowledge outside of academic research and separate from the practice of transportation demand management might suggest that automobile use is fairly inelastic and that parking demand is predetermined. This perspective stems partly from the fact that parking is often plentiful and usually not paid for by users (*40*), which leads many people to expect free, convenient parking at every destination (*41*). The most common parking policies—minimum parking requirements—and the information on which they are often based also assume that almost all visitors will arrive by automobile (*42, 43*) and that demand is fairly inelastic. Although the evidence base for this approach is not particularly strong, these assumptions are widely held (*1*).

The mechanisms through which parking availability influences automobile use are fairly well understood. The influence of parking rests in the fact that parking price and availability affect the costs of driving, relative to other modes, in terms of time or money. A majority of the research in this area focuses on the effects of parking price, rather than its availability (*4–6, 11, 37–39*). Generally, when parking costs are paid directly by the user, she or he can make a more informed mode choice and trip-making decisions. Less research has considered the influence of parking availability, but the existing studies point to a similar effect (*7–9, 11, 32, 36, 37*). As parking becomes less available and search times increase, people are less willing to give up their parking space or search for a new space and instead choose alternative modes or change their trip-making behavior in other ways—for example, by parking once and walking to multiple destinations instead of making multiple trips by automobile.

The influences of parking price, in particular, are widely recognized in tools for estimating travel demand and mode share, even if they are seldom reflected in parking policies. The Oregon Sustainable Transportation Initiative greenhouse gas reduction toolkit and the Oregon Department of Transportation Mosaic planning tool assume that priced parking can reduce vehicle miles traveled by 0.8% to 1.8% over a period of 20 years (*44*). The U.S. Environmental Protection Agency COMMUTER model accounts for parking costs in estimating automobile versus transit mode shares (*45*). The Florida Department of Transportation model for trip reduction impacts of mobility management strategies, which is used to estimate travel demand reductions for different policy levers, includes parking price elasticities (*46*). Its worksite trip reduction model accounts for priced parking and other parking management strategies in estimating the impacts of employer-based trip reduction programs (*47*).

Experiment

A randomized controlled experiment is typically the preferred method for establishing causality. However, in the context of urban policy, perhaps even more than in epidemiology, controlled experiments are extremely difficult to conduct.

Nonetheless, some known quasi-experiments exist. As Bradford Hill suggests, these are instances of preventive measures—that is, restrictions on parking availability—that lead to apparent decreases in automobile use. Many of these quasi-experiments occur when employers implement parking restrictions, either because of limited availability or as part of a transportation demand management program.

In Hartford, for example, a majority of the city's largest employers offer free parking to employees. Rates of automobile use at those companies are between 83% and 95%. One major insurance company, however, now charges employees a monthly fee in order to manage parking demand. At that location, only 71% of employees drive alone to work (*12*). Other employers and parking districts in different locations have experienced similar outcomes (*11*). The Hartford example, however, is particularly important to consider since it is one of the more automobile-oriented cities in this study. It can be reasoned that similar measures, if replicated across the city, could have a substantial effect on commuter automobile use.

Analogy

Bradford Hill says little about the use of analogy in judging whether a relationship is causal, except the following: "With the effects of thalidomide and rubella before us we would surely be ready to accept slighter but similar evidence with another drug or another viral disease in pregnancy" (*22*). Other researchers interpret this statement to mean that if one treatment has been shown to produce a particular outcome, less evidence is needed to show that similar treatments could produce a similar effect (*23, 24*). However, the use of analogy as evidence has also garnered criticism (*24*).

In the fields of urban and transportation planning, analogy is a particularly challenging criterion to satisfy. Many land use and transportation factors are known to affect travel behavior (*48*), so the effects of parking should not take any great leap of the imagination. However, many of these factors are also interrelated rather than analogous. With that taken into account, as well as criticisms of the criterion in general, it was considered only partially met but not particularly applicable.

IMPLICATIONS FOR PARKING POLICY

According to Phillips and Goodman (*25*), Bradford Hill looked at the decision-making process through an economic lens and believed in weighing the potential costs and benefits of a policy decision before acting on any piece of evidence, however strong or weak that evidence may be. In the current case, the costs of providing abundant parking without charging its users directly are too high to be overlooked, particularly in urban areas (*3*). These include costs with associated land acquisition, construction, maintenance, and operations, plus added impacts like traffic congestion (*49*), environmental degradation (*50*), lost tax revenues (*51*) and other externalities (*52*). In contrast, as noted by Weinberger, there is little evidence that parking restrictions hurt urban areas economically and some evidence to suggest that parking capacity and economic decline are actually associated (*8*). Voith finds that abundant parking in urban areas is more likely to be a sign of economic distress than a competitive advantage, arguing that cities generally should not encourage adding parking capacity in their central business districts (*53, 54*).

Application of the Bradford Hill criteria to understand the causal nature between parking provision and automobile use in American cities poses some challenges. For example, not every criterion can be thoroughly evaluated with the available data. This problem is due in large part to a general lack of studies aimed at answering this particular research question. This shortcoming suggests that more research might be necessary to satisfy the most rigorous scientific standards for inferring causality. The challenge is made even more complicated because the relationship between parking and driving, as with many factors in urban planning, is complex and because reliable data about parking are so rare.

In light of all the available evidence, however, there is a strong case for restricting and reducing parking capacity in urban areas, particularly as a means of curbing high levels of automobile use. The Bradford Hill criteria provide a framework to infer with a reasonable amount of certainty that parking increases have contributed substantially to rising automobile use in cities.

CONCLUSIONS

For this study, original data from nine U.S. cities over a period of 40 years were combined with knowledge gained from prior research in order to apply the Bradford Hill causality criteria and better understand the influence of parking provision on automobile use. At the city scale, it was found that an increase in parking provision from 0.1 to 0.5 parking space per resident and employee is associated with an increase in commuter automobile mode share of roughly 30 percentage points. It was also demonstrated that a majority of the Bradford Hill criteria can be satisfied by using the available data. Although there is some lack of relevant data and research, none of available evidence conflicts with the Bradford Hill criteria. On the basis of this knowledge, it is inferred that parking provision in cities is a likely cause of increased driving among residents and employees in those places. Given the costs associated with parking and its apparent effects on automobile use, these findings suggest that policies to restrict and reduce parking capacity in cities are warranted.

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