Explaining transit ridership: What has the evidence shown?

B. D. Taylor* and C. N. Y. Fink

What explains transit ridership? The answer to this simple question is both obvious and complex. Public transit systems carry large shares of person travel in older, larger metropolitan areas around the globe, but in most places, old and new, large and small, transit is losing market share to private vehicles. A host of factors no doubt influence transit ridership, including fares, routing, service frequency, stop/station accessibility, safety, private vehicle ownership levels, population density, land use, parking availability, and cost. But the relative importance of these factors and the ways they influence one another is less well understood. At the same time, the relationships between these factors and transit ridership are central to public policy debates about transportation system investments and the pricing and deployment of transit services. The research explaining transit ridership is surprisingly uneven, spanning a variety of methodological approaches, data sources, and variables that produce, perhaps not surprisingly, somewhat ambiguous, contradictory, and inconsistent results. Yet the factors affecting transit ridership are not simply matters of academic interest. Public investment in transit is waxing in response to the many problems of auto dependence, worsening traffic congestion, rising fuel prices, vehicle emissions, and so on. What can be done to increase patronage and better leverage these investments? To address this question, this paper reviews research on transit use, critiques the sometimes significant weaknesses in much of the previous work on this topic, draws conclusions from the more rigorous studies about which factors most influence transit use, and presents recommendations for future research.

Keywords: Transit, Ridership, Travel demand

Introduction

What factors affect public transit ridership? More specifically, which significant factors are within the purview of transit operators and which lie outside of their control? While large numbers of people use transit in metropolitan areas around the world, public transit systems in the United States have for decades been losing out to private vehicles. Levels of public transit use began to decline in the 1910s, peaked briefly during and just after the Second World War, declined substantially during the 1950s and 1960s, and have remained relatively steady in absolute terms since. The various modes of public transport carried almost 23·5 billion unlinked passenger trips in 1946, compared to just 10·4 billion trips in 2009 (American Public Transportation Association, 2011), a 56% decline over a period when the US metropolitan area population increased 10·4% to 233 072 833 (US Census Bureau, 2010). In terms of market share, the declining role of public transit has been even more pronounced; personal travel today is dominated by private vehicles (83·4% of trips in 2009), compared with 10·4% of trips made by foot, 4·2% by other modes and just 1·9% on transit (US Department of Transportation, 2011).

A multitude of factors influence transit ridership, including fares, routing, service frequency, stop and station accessibility, safety, private vehicle ownership levels, population density, land use, and parking availability and cost, among other things. However, the relationships between these factors and the ways in which they influence one another are less well understood. At the same time, these factors and their roles in affecting transit ridership are central to public policy debates about investments in transportation infrastructure, as well as the pricing of transit services and the management and operation of systems. In general, the research explaining transit ridership is uneven, spanning a variety of methodological

Institute of Transportation Studies, UCLA Luskin School of Public Affairs, 3250 Public Affairs Building, Los Angeles, CA 90095-1656, USA

*Corresponding author, email btaylor@ucla.edu

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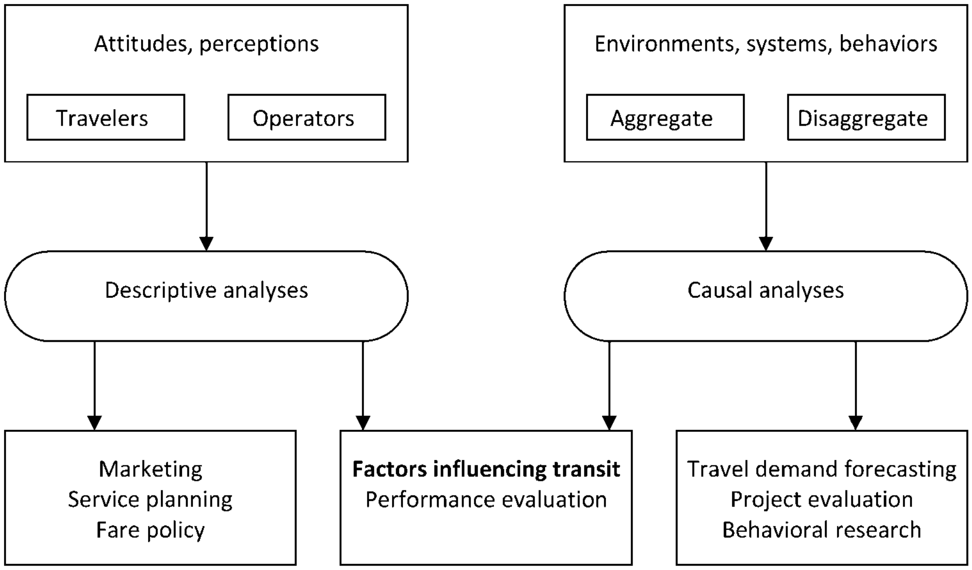

1 Taxonomy of research on transit ridership

approaches, data sources, and variables with a literature reporting often ambiguous, contradictory, and inconsistent results.

The factors affecting transit ridership are not simply matters of academic interest. Public investment in transit is waxing in response to the many problems of auto dependence, worsening traffic congestion, rising fuel prices, vehicle emissions, and so on. Local, state, and federal transit subsidies have skyrocketed in recent years, from \$16·2 billion (2009\$) in 1999 to \$26·7 billion in 2009, a remarkable inflation adjusted increase of 64% (American Public Transportation Association, 2011). Transit use has increased during this period of waxing transit investment, but much more slowly than the growth in public expenditures: unlinked passenger trips on transit increased by 13·2% between 1999 and 2009 (American Public Transportation Association, 2011). What can be done to increase patronage and better leverage these investments? To address this question, this article reviews research on transit use, critiques the sometimes significant weaknesses in much of the previous work on this topic, draws conclusions from the more rigorous studies about which factors most influence transit use, and presents recommendations for future research.

Descriptive and causal analyses: different methodological approaches to explaining transit ridership

We begin with a taxonomy of the transit ridership literature to show the different ways in which researchers have approached this topic (Fig. 1). Broadly, studies of transit ridership fall into two categories: research that focuses on attitudes and perceptions, with travelers or transit operators as the units of analysis and studies that examine the environmental, system, and/or behavioral characteristics associated with transit ridership. This second category includes both aggregate studies that use geographic area data as explanatory variables and transit systems as the units of analysis, and disaggregate studies that focus on the individual mode choice decisions of travelers. We review in this article a wide range of studies, but focus particularly on the descriptive analyses and aggregate causal analyses, and not on the broader, and enormous, literature on individual or household travel behavior or mode choice. The studies discussed in this paper examine specifically the factors influencing transit use, and not mode choice decisions more broadly; these factors are represented in the middle box in Fig. 1, where descriptive and causal analyses overlap in terms of focus.

In general, studies of attitudes and perceptions are descriptive in nature, while system focused studies tend to be structured as causal analyses. These two types of analyses also tend to have different consumers. Transit operators often use descriptive analyses for marketing, service planning and fare setting purposes. In contrast, transportation researchers tend to develop more empirical causal analyses for travel demand analyses, project evaluation, and behavioral research.

The transit ridership literature spans a variety of methodological approaches, including literature reviews, interviews, surveys, case studies, and cross-sectional statistical analyses. Descriptive analyses tend to examine more qualitative data and use information gathered directly from transit operators and/or their passengers. These data are often about perceptions of so called 'internal' factors (that is, internal to the transit system) related to transit ridership, including service improvements, fares, and marketing and outreach. Causal analyses, on the other hand, seek to develop explanatory models using, most often, regression analysis and a multitude of quantitative demographic, economic, and transportation variables, many of which (population density, employment levels, land use, etc.) are 'external' to the transit system and its managers. The different methodologies have their own advantages and disadvantages. Table 1 provides a summary of descriptive and causal analyses, the principal findings, and the main methodological weaknesses.

Descriptive analyses

Descriptive analyses are often based on sets of often interesting and rich qualitative data from surveys and interviews with transit operators and users, allowing researchers to identify the common factors thought to affect ridership. This perceptual information often focuses on factors internal to transit systems (like fares, service frequency, and the like), which is not surprising considering these are the elements most familiar and obvious to respondents. In general, transit managers surveyed and interviewed for such studies identify five categories of strategies believed to influence ridership: service adjustments and improvements, fares and pricing, marketing and information, collaborative planning approaches, and service coordination and consolidation (Transit Cooperative Research Program, 1995, 1997, 1998a, 2005, 2007). However, these studies pose concerns in terms of both methodology and interpretation. Such data can be highly subjective, dependent on respondents' perceptions, assumptions, and understandings about internal and external factors as they relate to transit systems and ridership, and subject to biases based on limited or incorrect information (Transit Cooperative Research Program, 1995, 1998a, b).

Other descriptive studies are vague regarding methodology, failing to outline the specific data collection processes researchers used to obtain information (Transit Cooperative Research Program, 1998b). Some of these studies are relatively old, most of them do not specifically ask respondents about perceptions of causality or the relative influence of internal factors (such as fares and headways) and external factors (such as population density or traffic congestion levels), and the asserted causal linkages between perceived factors and actual ridership are sometimes questionable (Sale, 1976; Abdel-Aty and Jovanis, 1995; Transit Cooperative Research Program, 1995, 1998a; Brown *et al.*, 2003). Finally, some studies examine the factors thought to increase transit patronage without considering and comparing the effect of such factors on systems that have flat or declining ridership (Sale, 1976; Hess *et al.*, 2002; Taylor *et al.*, 2002; Yoh *et al.*, 2003).

Causal analyses

Causal analyses have the advantage of being more sophisticated empirical studies of one, a few, or many agencies that allow researchers to analyze a wider array of data than those found in most descriptive studies. While studies examining one or a small number of transit systems do not yield widely generalizable results, they do allow more opportunity for the development and testing of sometimes sophisticated conceptual models of transit use (Hendrickson, 1986; McLeod *et al.*, 1991; Kain and Liu, 1995; Chung, 1997; de Witte *et al.*, 2006; Guo *et al.*, 2007). On the other hand, studies that use data on a large number of agencies produce more robust results and those results are more likely generalizable to other systems and metropolitan areas (Kain and Liu, 1996; Spillar and Rutherford, 1998; Hartgen and Kinnamon, 1999; Taylor *et al.*, 2009b). However, the models in causal analyses are often not fully specified and lack consistency in the variables operationalized and included, as Holmgren (2007) notes in a meta-analysis of public transit demand research which finds that such models should include car ownership, gas prices, level of transit supply and income data, but frequently do not. In addition, studies vary widely in the types of modes examined with some focusing specifically on rail or bus (Kain and Liu, 1995; Kain and Liu, 1996; Chung, 1997), whereas others consider multimodal systems (Hendrickson, 1986; Gómez-Ibáñez, 1996).

The data typically used in causal analyses have their own limitations. Studies of large numbers of transit systems tend to include readily available data from the US Census, the American Public Transportation Association and the National Transit Database (Hendrickson, 1986; Kain and Liu, 1996; Spillar and Rutherford, 1998; Hartgen and Kinnamon, 1999). However, the accuracy of monthly and

Table 1 Comparison of descriptive and causal analyses

	Descriptive analyses	Causal analyses
Typical research approach	Use survey, interview, and case study data	Create multivariate regression models that include combinations of variables internal and external to the transit system
Principal findings	Studies based on operators' perceptions tend to emphasize internal factors: service improvements and adjustments; fare innovation and changes; marketing and information; new planning approaches and partnerships; service quality and coordination	External factors tend to have greater effects than internal factors; among internal factors, service quality is more important than fares
Methodological weaknesses	Data are highly subjective; biases based on limited or incorrect information; data collection processes often not outlined in detail; questionable causal linkages; no questions about perceived causality; many studies are old	Generalizability is limited due to mostly small sample sizes; inadequate model specification due to relying on readily available data; most look only at unlinked trips rather than linked trips; some studies only consider work trips; problems with multi-collinearity between individual variables; endogeneity problems between service supply variables and demand; some variables are hard to quantify; many promising variables are not included in models

annual data from the American Public Transportation Association and National Transit Database can be an issue because some transit agencies fail to report statistics on time, or fail to report at all, leaving gaps in the data. Further, nearly all studies look only at unlinked trips (Hendrickson, 1986; McLeod *et al.*, 1991; Kain and Liu, 1995; Gómez-Ibáñez, 1996). Linked trips, which measure travel door-to-door rather than from transit link to transit link travel, more accurately reflect trip making behavior via transit, but because linked trip data are difficult to collect, and often unreliable when collected, researchers rarely analyze them. One exception is a study by McLeod *et al.* (1991) that develops a multivariate time series regression model for Honolulu, Hawai, using linked trips. While public transit carries a larger share of journey to work trips than other types of trips, an exclusive focus on commuting also provides an incomplete picture of transit use (Hendrickson, 1986; Morral and Bloger, 1996).

Further, there are persistent problems of endogeneity between service supply variables and demand. While transit use is, to a large extent, a function of transit service supply, transit service supply is also largely a function of transit demand. Transit operators in practice often respond to changes in transit use by adjusting the level of supply, which in turn affects transit consumption; the causality link between supply and consumption thus moves in both directions. Therefore, analyses concluding that transit service levels largely explain transit ridership levels tell us little about the underlying causality of transit use and can produce biased and inconsistent results (McLeod *et al.*, 1991; Liu, 1993; Kain and Liu, 1995; Gómez-Ibáñez, 1996). In an attempt to address issues of endogeneity, researchers have employed a variety of analytical techniques. Gaudry (1975) uses a recursive model in which only the ridership level of the previous year, not the current year, affects the level of supply. In order to solve the demand and supply equations separately, Peng *et al.* (1997) and Taylor *et al.* (2009b) employ multistage regression models using instrumental variables. Alperovich *et al.* (1977) and Kemp (1982) use structural equation models to relate variables of demand, supply, and service quality with one another. (Interestingly, Liu (1993) compares coefficients from structural equation ridership models with those obtained in single equation models in his study of Portland and concludes that the simultaneous effect between transit demand and supply is likely small.) Kyte *et al.* (1988) use simultaneous equation transfer function models to conduct a time series analysis. Most of these studies consider the simultaneity of transit demand and supply to develop time series analyses for particular agencies (Gaudry, 1975; Alperovich *et al.*, 1977; Kemp, 1982; Peng *et al.*, 1997). These analyses can then form the basis of transit demand projections that agencies use to modify service levels and routes. While such time series analyses are certainly relevant to service planning for a given system, their results may not apply to other areas or systems.

Persistent issues of multicollinearity, or a high degree of correlation among independent variables in models, plague causal analyses of transit ridership. Multicollinearity occurs both among various spatial variables and between spatial and socioeconomic variables. For example, a given variable – such as low population density – will likely be highly correlated with other characteristics such as segregated land uses and ample free parking. Areas with higher densities and multifamily housing tend to have higher transit use, but also tend to be populated by lower income households with lower levels of automobile access. Untangling the correlation among various spatial and socioeconomic variables and the potential influence in statistical analyses thus poses significant methodological challenges.

Additionally, some important factors explaining transit ridership are hard to quantify into variables. For example, more complete measures of auto access and operating costs can capture the tradeoff between auto use and transit in a particular geographic area, but such data are very difficult to obtain. Transit driver friendliness and employee morale may also be important independent explanatory factors, but measuring them consistently across transit systems (or even within a single system) can prove very difficult. Further, models should include proper measures of transit service effectiveness and service quality, including reliability, comfort and convenience, but they usually just measure service frequency. While previous studies have in fact examined the effects of service quality measures like comfort and information availability on transit ridership, they typically use agency specific data that make it difficult to generalize across systems (Cervero, 1990; Dziekan and Kottenhoff, 2006; Smart *et al.*, 2008; Taylor *et al.*, 2009a; Iseki and Taylor, 2010).

Budget constraints importantly affect transit ridership, as demonstrated in Gómez-Ibáñez's (1996) study of transit deficits in Boston, but are rarely measured. Available funding may result in more or less transit service than would otherwise be warranted, affecting overall transit use. In addition, these modeling studies often suffer from information loss due to aggregation. Building density, household incomes, parking availability, route density, headways, and so on can vary dramatically over a transit service area; aggregating over larger geographies loses much of this variation. Fully understanding the determinants of individual transit mode choice requires disaggregate analyses at the household, individual, or even trip level, and then re-aggregated to estimate transit use at the system or metropolitan level. Such analyses are frequently conducted as part of transit patronage forecasting exercises, but less often in social science research, perhaps because they can be very data intensive and expensive to conduct (Bento *et al.*, 2003; Hu and Reuscher, 2004; Pucher and Renne, 2004; Nobis and Lenz, 2005; Polzin and Chu, 2005; Handy and Tal, 2006; Mohammadian and Zhang, 2006; Dill and Kanai, 2007; Rashidi *et al.*, 2009; Timmermans and Zhang, 2009).

Nature and nurture: external and internal factors explaining transit ridership

The descriptive and causal analyses described above each examine a host of factors related to transit ridership, and these factors can be broadly divided into two categories: external and internal. External factors are generally those not directly related to the transit system and its managers, such as service area population and employment levels. Such factors typically act as proxies for the large numbers of individual factors thought to affect transit demand. Internal factors, on the other hand, are those over which transit managers exercise some control, such as fares and service levels. Some authors use different terms for the categories of internal and external variables. For example, Kain and Liu (1995, 1996) refer to exogenous variables (external factors) and policy variables (internal factors).

The line separating internal and external factors is not always a sharp one. Population growth, for example, may change demand for transit services, which in turn may change the levels of service provision. While many transit managers may attribute increased ridership to service expansion and new programs, these changes in service are often in response to changes in demand. In fact, many agencies report that their principal obstacle to increasing ridership is lack of funding to increase service to meet rising demand. Nevertheless, most studies of transit ridership – both descriptive and causal – treat external and internal factors separately.

A European Commission on Transportation Research (ECTR) (1996) literature review of transit ridership enhancement projects draws a similar distinction between external and internal factors. The report categorizes an extensive list of variables used in previous studies into two groups, direct and indirect strategies. Direct strategies, such as changes in fare levels, service quality and quantity, and the adoption of new technologies, aim to increase the efficiency and effectiveness of transit operations. In contrast, indirect strategies are broader public policies thought to influence ridership, but over which transit agencies exercise little control. These strategies include such policies such as taxing car ownership and usage; area specific car use restrictions, including road pricing, parking costs and access restrictions; and other policies from land use planning to telecommuting to flexible working hours. The ECTR's distinction between direct and indirect strategies is roughly equivalent to the internal and external factors discussed here. The framework of internal and external factors outlined in this article differs slightly from the framework of direct and indirect strategies in the ECTR report (1996), because it can also include indirect factors unrelated to public policy, such as climate or topography. While this framework does not always appear in the literature, it nonetheless offers a useful lens for examining the factors that influence transit ridership.

External factors affecting transit ridership

Studies of transit ridership have tested the influence of a wide range of ridership influencing factors external to transit systems. We group and discuss these in three general categories below: socioeconomic, spatial and financial. In the first two of these categories, variables that directly or indirectly explain private vehicle accessibility and utility tend to be the most important factors. The relatively limited road capacity and expensive parking in places like Manhattan and downtown San Francisco decrease the relative utility of private vehicle use, and, correspondingly, increase the utility and use of public transit. In most places, however, transit functions as an 'inferior good' to private vehicles, such that the demand for transit service is largely determined by levels of private vehicle access. Therefore, in cities like Nashville or Birmingham, private vehicle access and utility are relatively high, and transit use is correspondingly low.

As public transit systems in most metropolitan areas have lost market share to private vehicles over the past century, the importance of two remaining transit travel markets has grown. The first is comprised of travelers with limited access to private vehicles, such as children, the elderly, the poor, and the disabled. The second market includes commuters to large employment centers, especially central business districts (CBDs) with limited or expensive parking (Transit Cooperative Research Program, 1998c). Therefore, in addition to direct and indirect measures of private vehicle access, which includes parking, employment variables, especially measures of central business district employment, are shown to significantly influence transit use.

Finally, research shows that funding for transit service, which reflects both demand for and popular support of public transit and economic vitality, has also been shown to influence transit use. Such research raises questions of circular causality similar to those raised by measures of transit service supply, as discussed in more detail below.

Socioeconomic and demographic factors

Studies identify and include a host of socioeconomic factors to explain aggregate transit ridership levels. Transit use has long been thought to be more sensitive than private vehicle use to changes in employment levels. One historical example of this is when transit patronage nationwide declined by over 25% during the Great Depression of the 1930s, yet private vehicle travel actually increased during the same period (American Public Transportation Association, 2011). Thus, researchers often use employment levels, both within regions and CBDs, in causal analyses of transit use.

Chung (1997) finds that between 1976 and 1995 employment and regional development had greater effects on ridership than fare levels for the Chicago Transit Authority system. Similarly, Gómez-Ibáñez (1996) finds that ridership in Boston between 1970 and 1990 was affected more by external factors beyond the transit agency's control than internal factors such as fares. Among external factors, employment has generally proven more significant than income in explaining transit use. Hendrickson (1986) examines the relationship between CBD employment levels and public transit use in a study of 25 large US metropolitan areas for 1970 and 1980, and finds that CBD employment explains a very high percentage of the number of transit work trips (R^2=0·96 and 0·90, respectively). Hendrickson (1986) also finds that CBD employment is a more important factor than regional population in explaining transit commuting levels. Finally, Kain and Liu's (1995, 1996, 1999) studies of ridership increases in Houston and San Diego identify large service increases and fare reductions as key factors, but also metropolitan employment and population growth. Kuby *et al.* (2004) also find employment, population and % renters within walking distance of transit stops and stations to be significant factors in light rail ridership. In interviews with a sample of transit agency officials, Yoh *et al.* (2003) expected that transit managers interviewed would cite agency policy and management initiatives as primary factors related to ridership levels; instead, officials more often pointed to influences outside of their systems such as population and employment growth.

Regression analyses of transit ridership frequently include income levels, as discussed above. Liu (1993) and McLeod *et al.* (1991) find that per capita income measures do influence, or at least closely relate to, ridership, while Gómez-Ibáñez (1996) uses a per capita income variable in one model and uses a time trend variable in another model that reflects a consistent trend in suburbanization and income growth. Gómez-Ibáñez (1996) concludes that the effect of rising incomes and suburbanization offset the positive effects of employment growth. This led to net ridership decreases, and substantial fare reductions and service increases were required to counterbalance this effect, significantly increasing deficits in the process.

Automobile ownership also strongly, and negatively influences public transit use. Liu (1993) and Kain and Liu (1995, 1996) include per capita passenger car registrations and percent carless households as variables in their regression models for various metropolitan areas. However, because car ownership, car use, and transit use are interrelated, a change in one variable affects the others even though the magnitude of effect may not be symmetrical in terms of direction. Kitamura (1989) examines the causal relationships between car ownership, car use, and transit use using surveys and trip diaries for nearly 4000 people in the Netherlands. He finds that changes in car ownership lead to changes in car use, and, in turn, to changes in transit use. He also finds that the reverse relationship, where changes in transit use lead to changes in car use, is weak, and concludes that improving transit may not suppress increases in car use among car owners.

Many comprehensive transit ridership models also include the price of gasoline based on the assumption that high gasoline prices will encourage people to use transit (McLeod *et al.*, 1991; Liu, 1993; Kain and Liu, 1995, 1996; Maghelal, 2010). Indeed, the media speculated that spikes in fuel prices in recent years were associated with increases in transit use (Bello, 2008; Krauss, 2008; Cooper, 2009). The research generally finds, however, that gasoline prices have a relatively small influence on transit ridership, because fuel prices represent only a small share of overall automobile operating costs (Small and van Dender, 2005, 2006). Haire and Machemehl (2007) find the relationship between fuel prices and transit ridership to be statistically significant in five cities across the US and Chen *et al.* (2011) identify gas prices as a significant factor, albeit asymmetric in that rising gas prices encourage transit ridership but falling prices do not discourage it much. One study that examines fuel prices in isolation from other factors found sensitivity to gas prices at low to medium levels in the US (Currie and Phung, 2007). Sale (1976), however, studied the effects of fuel price increases sparked by the energy crisis of the early 1970s and finds that these fuel price increases had an immediate and positive effect on increasing transit ridership.

More recently researchers have examined the impact of a growing ridership demographic, immigrants, on ridership levels. Blumenberg (2007) examines the transit use of immigrants in California and finds that the 19% increase in transit commuters from 1980 to 2000 was due almost entirely to immigrants. However, projections show that the number of immigrants in California will increase more slowly in the years ahead; this combined with immigrants' relatively speedy assimilation to automobile use suggests that a significant and consistent source of new riders transit agencies in areas with large immigrant populations will decrease over time, and with it overall transit ridership rates (Blumenberg and Shiki, 2007). Chen *et al.* (2011) note that demographic changes, such as those related to immigrant populations, are important in understanding transit ridership factors; however, they were not able to include this variable in their analysis due to a lack of appropriate immigration data.

Spatial factors

A large and growing body of recent research examines the relationships between transportation systems, land use and urban form, and travel behavior. Researchers have devoted significant attention to land use because policy makers and planners have some direct control over land use and transportation system deployment, unlike many of the socioeconomic factors discussed above. Further, the New Urbanist planning movement has captured the imagination of many scholars and practitioners, prompting research on the effects of New Urbanist principles, compact, mixed use developments and dense, interconnected street and sidewalk networks, on travel behavior (see, for example, Ewing, 1999; Ewing *et al.*, 2005, 2006; Hendricks, 2005; Khattak and Rodriguez, 2005; Transportation Research Board, 2005, 2009; Dill, 2006; Handy, 2006; Leck, 2006; Rodriguez *et al.*, 2006; Baran *et al.*, 2008; Joh *et al.*, 2008; Chatman, 2009).

Perhaps no aspect of land use and urban design affects the relative utility of automobile use more than parking availability and pricing. Several studies show that parking availability strongly influences transit ridership. In one study, researchers specifically examine the relationship between parking strategies and transit ridership (Transit Cooperative Research Program, 1998b). They consider various strategies, including increasing the cost of parking, changing parking regulations, cashing out employer-provided parking, and implementing transportation demand management programs. They find that taxing parking spaces most effectively shifts mode share to transit. Morral and Bloger (1996) find a strong relationship between the number of downtown parking stalls per CBD employee and the transit modal split in Canadian cities. Using regression analysis, Chung (1997) also finds that parking availability is the single most significant external factor affecting ridership with an increase in 1 million spaces per year resulting in a decrease in ridership of 2·7 million transit trips. Other studies have shown that strategies to increase parking costs or the probability that drivers will have to pay for parking are more effective in increasing transit mode share than strategies to increase the frequency or accessibility of transit service (Shoup, 2005a, b; Mukhija and Shoup, 2006). Such studies suggest that combinations or 'packages' of parking strategies will be most effective in increasing transit ridership.

Despite the strong observed relationships between parking and transit use, most research on urban form and transit use has focused on other spatial factors. In particular, researchers have long thought that residential and employment densities are critical determinants of transit use (Pushkarev and Zupan, 1977; Nelson\Nygaard Consulting Associates, 1995; Spillar and Rutherford, 1998). Others have hypothesized that the effects of land use mixes and urban design are important factors as well (Pushkarev and Zupan, 1977; Hendrickson, 1986; Cervero, 1993; Transit Cooperative Research Program, 1996; Spillar and Rutherford, 1998; Crane, 2000). Collectively, these studies find that decentralized residential and occupational locations are difficult to serve with traditional fixed route public transit because transit works best when a large number of people are traveling to and from concentrated nodes of activities.

Not surprisingly, these land use focused transit patronage studies also find that dense, compact development is more conducive to transit use than dispersed, sprawling urban development. Nelson\Nygaard Consulting Associates (1995) analyzes transit demand in Portland, Oregon using 40 land use and demographic variables. Among these variables, housing and employment density per acre are found to be the most important for determining transit demand. Similarly, Pushkarev and Zupan (1977) find that residential densities in transit corridors, together with the size of the downtown area and the distance of transit stations from downtown, explain the level of demand for a variety of transit modes. Likewise, Spillar and Rutherford (1998) estimate the relationship between urban residential density and transit ridership; they find that transit use per person grows with density, up to a ceiling of 20 to 30 people per acre and 0·1 to 0·2 daily per capita transit trips.

Recent work by Brown and Thompson has sought to challenge the conventional wisdom that fixed route transit functions poorly in decentralized areas (Thompson and Brown, 2006; Thompson *et al.*, 2006; Brown and Thompson, 2008a, b, c). In one study, Brown and Thompson (2008a) analyze aggregated transit data for 73 metropolitan statistical areas in 2000 and find that, while transit service productivity has declined overall since 1990, it has not declined more rapidly in metropolitan statistical areas that have decentralized their transit system services. Brown and Thompson (2008a) also estimate two time series models of transit use in Atlanta from 1978 to 2003 to show that transit use and productivity can actually improve if transit managers decentralize transit system services, arguing that grid-like transit networks better service increasingly dispersed origin–destination pairs in most cities.

Finally, a very small number of studies have attempted to determine the effects of weather on transit ridership. Guo *et al.* (2007) uses weather and transit data from the Chicago Transit Authority to construct a number of regression models in which temperature, rainfall amounts, wind speed, and fog usually have statistical significance. Another study of Chicago also finds that adverse weather was a significant variable in transit ridership (Tang and Thakuriah, 2012). Kuby *et al.* (2004) incorporate a climate variable into a transit ridership model that includes land use and demographic variables. They find that more extreme climates, measured by average deviation from a 65°F base temperature, have a statistically significant negative effect on ridership. Cravo *et al.* (2009) examines the impact of weather on the New York City Transit system's revenue and ridership. Although the researchers chose to focus on revenue rather than ridership and found differences between particular modes and days of the week, they identify temperature, snow and rain as significant variables accounting for about one-quarter to over 60% of the variation in revenue. Despite such findings, it remains unclear whether inclement weather has a positive or negative influence on transit ridership for a specific agency: some agencies report that ridership increases during bad weather, while others report decreases (Khattak and Palma, 1997).

Finance factors

Research has shown that transit subsidy levels have an important influence on transit ridership. At the same time, the level of transit demand surely helps to explain political support for transit subsidies. Sale (1976) finds that the availability of substantial and stable financial resources influences transit ridership levels. Gómez-Ibáñez (1996) includes a dummy variable in his regression models for years that Boston's transit agency experienced severe budget crises; this variable proved statistically significant and had the expected negative sign. Kain and Liu (1996) find that public versus private operation of transit systems influences cost efficiency and, in turn, ridership. In comparing transit policies in the United States and Germany, Buehler (2009) suggests that the higher ridership levels and broader cross-section of the population using transit in Germany are partly due to a longer history of transit subsidies and more efficient use of these funds.

Internal factors affecting transit ridership

While external factors have substantial influence on transit ridership, internal factors related to the provision of service also play a substantial role. Transit agencies have several options for attracting riders; these include the setting of fares, configuring the density and reach of route networks, the siting and quality of stops and stations, service frequency, and service quality. Studies that attempt to determine the influence these options relative to one another, and relative to external factors, are naturally of great interest to transit operators.

Studies draw differing conclusions about the relative explanatory strength of internal and external factors. Kain and Liu (1995) find that the relative effects of internal factors depended on the area studied: whereas transit service miles had the greatest effect in determining transit use in Houston, rapid regional growth had the greatest effect in San Diego. Even studies that emphasize the importance of external factors note that transit agencies can still exert considerable influence over ridership numbers. Taylor *et al.* (2009b) find external factors explain much of the overall level of transit use in an urbanized area. However, transit policies are not inconsequential, with fares and service frequency accounting for ~26% of the observed variance in per capita transit patronage in urbanized areas across the United States.

Pricing factors

Pricing and fare levels are the most frequently analyzed internal factors in studies of transit use. In a study of seven systems that experienced ridership increases of 5% or more between 1971 and 1975, Sale (1976) finds stable or declining fare levels to be an important factor, albeit secondary to service expansion. Liu (1993) and Kain and Liu (1995) include fare variables in regression models for ridership in Portland, San Diego and Houston; they find that fares, as part of a combination of internal factors and external factors including employment, gas prices, and service quantity, contribute significantly to transit ridership. In the case of Portland, fare reductions together with service expansion were primary factors in a dramatic increase in ridership during the 1970s (Liu, 1993).

Kain and Liu (1996) conducted econometric analyses of factors influencing transit ridership for 184 systems over a 30-year period between 1960 and 1990. Their findings show the mean fare elasticities for ridership changes during each decade ranged from −0·34 to −0·44, and the mean revenue mile elasticities ranged from 0·70 to 0·89. These results imply that transit frequencies will increase ridership more by increasing service than by reducing fares, although either change will likely reduce the transit system's overall cost effectiveness. Other researchers have similarly found fares to be a statistically significant variable in ridership models (McLeod *et al.*, 1991; Kohn, 2000; Taylor *et al.*, 2009b; Chen *et al.*, 2011).

A few studies find that special pricing schemes, such as deep discounting, can induce significant ridership increases, because they account for the different price sensitivities of different market segments. Some transit agencies, for example, have successfully increased ridership without increasing service by partnering with universities and providing discounted transit fares to students (Meyer and Beimborn, 1998; Transit Cooperative Research Program, 2001; Brown *et al.*, 2003).

Service quantity factors

Transit service quantity variables, in particular service coverage and service frequency, are another important set of factors influencing transit ridership. Much of this research has shown that service quantity factors are even more significant than pricing factors (Cervero, 1990; Taylor *et al.*, 2009b). In their multiple regression analyses, Liu (1993) and Kohn (2000) find that revenue vehicle hours of service are strongly associated with transit use. Kain and Liu (1995, 1996) and Gómez-Ibáñez (1996) find that revenue vehicle miles of service are also significantly related to transit ridership. Kuby (2004) finds that the number of bus connections and park and ride facilities, as well as the centrality of stations, are significant ridership factors. Finally, McLeod *et al.* (1991) incorporate the number of buses in the fleet, as well as a dummy variable for service disruptions due to strikes, into their ridership models of Honolulu, Hawai'i. While these factors are statistically significant, they find fare elasticities of −0·56 and −0·61 and service elasticities of 0·25 and 0·28. This suggests a decrease in fares in Honolulu will produce a greater ridership increase than an increase in service, the opposite of Kain and Liu's (1996) findings for Houston, Portland and San Diego.

Service quality factors

Several studies find that transit service quality factors, such as customer service, station safety, and information availability, are more important in attracting riders than transit service quantity factors or fare changes (Cervero, 1990; Taylor *et al.*, 2009a; Iseki and Taylor, 2010). In other words, service improvements may attract more riders than either fare decreases or service quantity increases. The results of Syed and Khan's study (2000) support Cervero's (1990) findings. Their factor analysis of the determinants of public transit ridership in Ottawa-Carleton, Canada, finds that service quality factors such as bus information, on-street service, station and *en route* safety, and customer service are more important than fare reductions. Litman (2008) and Iseki and Taylor (2009) find that improved transit travel conditions can decrease perceived travel time unit costs at the same level as a travel speed improvement.

The transit travel experience outside of buses and trains has been a growing focus of transit patronage research. The configuration of route networks, the location of and access to stops and stations, the frequency and length of transfers, and amenities and information at stops/stations have all been shown to significantly affect transit use (Brown and Thompson, 2008a, b; Iseki and Taylor, 2009, 2010; Lei and Church, 2010; Guo and Wilson, 2011; Lei *et al.*, 2012; Yoh *et al.*, 2012). In general, studies of transit traveler behavior find that users perceive walking, waiting, and transfer time as far more onerous than in-vehicle travel time, suggesting that improving the out-of-vehicle transit travel experience, such as through more adroit stop/station siting and by providing accurate 'next bus/train' information at stops/stations, is likely to be a particularly cost effective ways boost patronage.

Other service quality measures have been shown to affect ridership. Although in his analysis of systems in seven cities Sale (1976) attributes most ridership gains to service expansion, fare reductions, and external factors, he does discuss various indirect and seemingly successful actions many of these agencies employ to improve service quality. These include transportation systems management, route structuring less oriented to CBDs, coordinated arrivals and departures at focal points, ongoing operations planning and evaluation, and the development of effective organizational structures. Abdel-Aty and Jovanis (1995) and Abdel-Aty (2001) explore a different aspect of service quality influencing transit ridership. Using binary logit and ordered probit model estimates, they find that transit information delivered via intelligent transportation systems can encourage shifts to transit, including non-transit users who would consider transit if certain information items were available. A study of the impact of real-time bus information systems on ridership in Chicago finds that bus tracking technology did increase ridership, but the average increase was modest and a host of other variables (fares, service attributes, gas prices, unemployment levels, and weather conditions) are also significant (Tang and Thakuriah, 2012). Jia (2009) examines ridership growth on the Washington Metropolitan Area Transit Authority system and concludes that service enhancements, including special event service, connections to bus service during off-peak trips, and improved pedestrian and bicycle access, are a significant contributing factor in addition to more regional land use and urban revitalization efforts.

Conclusion: What do we really know and what are the next steps?

Transit use is a function of a very wide array of factors both internal and external to transit systems. These many factors have been evaluated in the numerous studies reviewed here, but in an inconsistent and asymmetric fashion. Which have proven most important? Variables that directly or indirectly measure automobile access and utility, such as auto ownership and parking availability, have consistently been found to explain more of the variation in transit ridership than any other group of variables. As most US metropolitan areas are dominated by private vehicle travel, it should come as no surprise that policies affecting driving also strongly affect transit use. Next, macro-economic factors, such as employment levels, central business district employment, and household income, explain substantial portions of transit use. While poorer people tend to use transit more, low unemployment, large, vibrant downtowns, and rising incomes all tend to increase transit use. Finally, spatial factors, such as population density, employment density, and traffic congestion levels, are shown in many studies to explain much variation in transit ridership. However, the collinearity among these variables – and their collinearity with other variables related to transit use, raises questions about the direction of cause and effect, and about the relative influence of the measured factors on transit ridership. For example, dense, crowded cities increase the utility of fixed route, fixed schedule transit to service, but their congested streets and expensive parking also reduce the utility of private vehicle travel as well.

With respect to factors internal to transit systems, improvements in service have generally been shown to be more important than pricing in determining ridership. However, most research has measured service supply rather than service quality; the fewer number of studies that have measured service quality (such as schedule adherence) have found that it can have an even greater influence on ridership levels than service quantity. Studies of service and price elasticities generally find that traveler responses to service changes tend to be more elastic than to fare changes. That said, most research on fare elasticities has focused on the effects of fare increases (often in concert with service cuts) and not other changes to fares. However, focused fare programs aimed at specific populations, such as targeted discounts for students and the transit-dependent, have in many cases proven to be effective in attracting riders.

To sum, transit ridership is largely, though not completely, a product of factors outside the control of transit managers. That is the 'nature' of transit operating environments explains more about transit use than the 'nurture' of those services by transit system managers. Among the factors that transit systems do control, the quantity (e.g., headways) and quality (e.g., schedule reliability) of transit service and adroit pricing of transit services to target particular travel markets have proven most effective at stimulating ridership.

While many of the factors found to most affect transit ridership are outside the control of transit managers, they are not beyond the bounds of public policy. Policies that support private vehicle use, such as highway investments, low motor fuel taxes, and minimum parking requirements, greatly affect transit use, more in many cases than policies to encourage transit use. In addition, while planners in many cities are working hard to create more transit friendly environments, transit remains an 'inferior good' for most metropolitan trips and is often the mode of last resort because private vehicles offer travelers levels of speed and flexibility that traditional fixed route transit can rarely match. Thus, the utility of private vehicles, combined with the array of public policies that encourage their use, explains more of the variation in public transit patronage than any other family of factors.

Adopting policies to reduce the relative utility of private vehicles would bode well for public transit ridership, but neither discouraging trip making in general nor maximizing transit ridership in particular are meaningful public policy goals on their own. On the other hand, most economists would agree that maximizing social welfare is the most important goal of transportation policy, and that altering automobile friendly policies so that drivers fully compensate society for the significant externalities they impose by driving would cause people to be more judicious in their use of private vehicles, and would almost certainly make public transit more attractive to many more travelers.

Finally, the findings of the many descriptive, perceptional studies reviewed here are generally consistent, but many suffer from problems of self-selection bias and improperly implied causality. On the other hand, many (though certainly not all) of the causal analyses reviewed suffer from problems of aggregation, failure to articulate conceptual models of transit use, high levels of collinearity among independent variables, and endogeneity problems between service supply variables and service consumption. To address these shortcomings, future work on transit use should focus on more sophisticated models (using instrumental variables, simultaneous equation, and structural equation) with more conceptual grounding based on the parallel scholarship on mode choice modeling. Researchers should also test their models for predictive power, which has rarely been done in the scholarly literature. But regardless of their analytical rigor, failure to translate these analyses into meaningful terms for practitioners means that transit system managers will continue to rely primarily on word of mouth, experience, and descriptive analyses in setting policies and planning service for the foreseeable future (Yoh *et al.*, 2012).

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