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An evaluation of the accessibility benefits of commuter rail in Eastern Massachusetts using spatial hedonic price functions

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Abstract. We estimate spatial hedonic price functions to examine local and regional accessibility benefits of commuter rail service in Eastern Massachusetts, while controlling for proximity-related negative externalities and other confounding influences. The data include 1,860 single-family residential properties from four municipalities with commuter rail service, and three municipalities without commuter rail service. We find some evidence of the capitalization of accessibility to commuter rail stations. Two model specifications suggest that properties located in municipalities with commuter rail stations exhibit values that are between 9.6% and 10.1% higher than properties in municipalities without a commuter rail station. With a third model we detect weak evidence of the capitalization of auto access time or walking time to the stations, suggesting that properties located within a one-half mile buffer of a station have values that are 10.1% higher than properties located outside of this buffer area and that an additional minute of drive time from the station is related to a decrease of 1.6% in property values. Our results also indicate that proximity to commuter rail right-of-way has a significant negative effect on property values, which suggests that for every 1,000 ft. in distance from the commuter rail right-of-way, property values are between $732 and $2,897 higher, all else held equal. At the mean sample values, this result translates into an elasticity of between 0.03 and 0.13, depending on the functional form of the hedonic price equation.

1. Introduction

Despite cases like Stockholm and Copenhagen, where commuter rail services are the axes around which these cities have developed over the last 50 years (Cervero 1998), recent experience in North America has shown that groups opposed to the introduction of commuter rail service are often successful in delaying or requiring substantial design modifications, many times resulting in significant cost to the project. Environmental impacts of commuter rail associated with the proximity of sensitive and often-incompatible natural environments and land uses to commuter rail facilities are of particular concern to many communities. Local opposition groups typically present a range of arguments in an attempt to support their position, many of which revolve around actual or perceived threats to property values, personal security, and neighborhood amenity. Although empirical evidence is limited, arguments related to possible threats to property values are understandable, since in the U.S. home equity is the primary source of household wealth for many families (United States Department of Housing and Urban Development 1995) and spending on housing comprises a significant portion of total consumption. Therefore, actual and perceived impacts of commuter rail service, and the consequent public reaction to such impacts, are a significant contributing factor in the transportation planning process. Misperceptions about such impacts by both property owners and by transportation agencies can lead to costly delays or misallocation of resources.

We define commuter rail here as local and regional passenger train service that operates within a metropolitan area, between a central city and its suburbs, with typically only one or two stations located in the central business district (CBD). Commuter rail service tends to operate as part of a regional system that is publicly owned, although independent contractors sometimes operate the service, on rights-of-way that are usually shared with freight and intercity passenger rail services. By providing high levels of service to suburban choice riders, many argue that commuter rail provides important accessibility, air quality, and economic benefits.

Although planners generally accept the predictions of urban economic theory that transportation improvements enhance accessibility and by doing so increase the values and the redevelopment potential of properties, there is a paucity of empirical evidence concerning the accessibility benefits of commuter rail service. When available, the preponderance of the published evidence fails to isolate the accessibility effects from the proximity-related impacts. Thus, a systematic study attempting to isolate the accessibility impacts will be helpful for substantiating or disproving the potential of commuter rail as a catalyst for land development. Additionally, such evidence can be useful in other ways, such as mediating legal controversies surrounding the impacts of planned commuter rail extensions, which have become prominent in the U.S., and for highlighting the feasibility of using revenue-generating tools that hinge on the capitalization of the accessibility benefits of transit service.

The lack of empirical evidence, combined with the continued growth in commuter rail service and the contentious debate regarding its impacts, are the primary impetus for this research. In this paper we examine the local and regional accessibility benefits of commuter rail service as capitalized into the property values of single-family residential properties, while attempting to control for proximity-related negative externalities associated with the rail service. We rely on digital orthophotography and on geographic information systems to measure accurately both multimodal accessibility to commuter rail stations, and distance from the rail right-of-way. Our study is part of a broader research effort evaluating the nature and extent of beneficial and deleterious impacts of commuter rail systems upon communities and property owners.

Although the analysis is somewhat limited by the well-known difficulties of estimating welfare measures with hedonic models, we obtain consistent estimates of the relationship between local and regional accessibility to commuter rail and property values. The paper is divided into five additional sections. In the next section, we summarize prior empirical evidence regarding commuter rail benefits and property values and provide initial hypotheses for the study. The third and fourth sections discuss the hedonic analysis methodology employed, and the data collected. Results of the empirical analysis and conclusions are provided in the last two sections.

2. Accessibility benefits of commuter rail

The literature on the accessibility benefits of commuter rail has relied on case studies, matched pair property comparisons, and hedonic models, with the majority of the recent evidence emanating from the latter. Perhaps the first empirical attempt to examine commuter rail's accessibility benefits is a widely cited and comprehensive study of the land use impacts of rail transit (Knight & Trygg 1977). The study relies primarily on previously published reports, interviews, aerial photos, and other secondary sources to review commuter rail service in six North American cities. Knight and Trygg (1977) detect positive accessibility benefits of commuter rail in Toronto and Philadelphia, whereas no benefits are found for Chicago, Boston, Montreal or New York City. These mixed results are consistent with those of Bernick and Carroll (1991), who rely on a survey of developers in the San Francisco area, and find inconsistent results regarding the perceived impacts of CalTrain stations upon rents in nearby multi-family housing developments.

Diamond (1980) utilizes the appraised value of single-family residential land obtained from home mortgage applications of 414 parcels sold between the years 1969 and 1971 in Chicago. He uses hedonic models to find that the marginal value of each additional mile of proximity to a commuter rail station, evaluated at the sample mean appraised lot value of \$21,700 in 1970 dollars, is \$460, which is an increase of approximately 2.1% for each additional mile. The corresponding elasticity of property value with respect to distance to a commuter rail station, evaluated at the sample mean distance from a commuter rail station of three miles and the sample mean appraised lot value is 0.0635.

In a more recent study, Voith (1991) uses data for 571 census tracts in the Philadelphia area. He finds that rail transit access is capitalized into house values, with a 3.5% premium of the 1980 median house value for tracts served by commuter rail. Of note is Voith's attempt to control for accessibility to locations away from the CBD. In a follow-up study, Voith found that access to rail stations on the Lindenwold Line in Philadelphia created an average housing value premium of 6.4% (Voith 1993). Similarly, Cervero and Duncan (2002b) examine the impacts of two commuter rail services in the San Francisco Bay Area. Though they find 20% value premiums for commercial properties in commercial business districts and within a quarter mile of a CalTrain station, they find no capitalization premiums for properties located in close proximity to the Altamont Commuter Express commuter rail stations, and surmise that this is the result of the newness of the Altamont service.

One complication that arises in the use of hedonic models to examine the accessibility benefits of commuter rail is the potential correlation that exists between local accessibility to a rail station and the presence of deleterious effects such as noise and vibration associated with the rail service. If these negative externalities are omitted from a hedonic model, then the parameter estimates for accessibility will be biased, partly because the hedonic price function may not vary monotonically with distance. Accounting for the need to separate positive, accessibility-derived influences from negative, proximity-induced impacts on values can be done with transformations on a distance variable, or by measuring distance to the commuter rail station separately from measuring distance to the right-of-way.

Two other studies have attempted to isolate the accessibility benefits of commuter rail from the negative effects related to proximity to the right-of-way and grade crossings. Landis et al. (1995) find that properties within 300 m of the CalTrain right-of-way experience a discount of about $51,000, which represents 15.3% of the mean sales price at the time, while Armstrong (1995) finds that homes located within 400 feet of Boston's Fitchburg commuter rail line experience a discount of 18.9%. Consistent with these findings, our first hypothesis is that the negative effects related to proximity to the right-of-way are important for properly quantifying the accessibility benefits of commuter rail service.

A second characteristic limiting the comparability of the accessibility benefits estimated in prior studies is how the concept of accessibility is defined and measured. While some studies define accessibility as one's ability to reach a local rail station (e.g. Gatzlaff & Smith 1993; Cervero & Duncan

2002b), others (e.g. Damm et al. 1980; Voith 1993) define accessibility as the line-haul travel time to particular destinations. Conceptually, one can consider accessibility as having local and regional components, with the local component measuring ease of access to stations and the regional component measuring commuter rail's ability to take riders to where they want to go (see Dimitriou 1992). Good access to a rail station is a necessary but not sufficient condition to enjoy the accessibility benefits of commuter rail. Commuter rail service must be able to competitively connect the station with desired destinations.

Despite this relatively simple observation regarding local and regional accessibility, most studies of the capitalization of rail accessibility benefits in land values (see for example, Gatzlaff & Smith 1993; Landis et al. 1995; McDonald & Osuji 1995; Forrest et al. 1996) have combined these two forms of accessibility into a single category of either local or regional accessibility. Other studies have measured local accessibility while controlling for regional accessibility by measuring proximity to the labor force (Cervero & Duncan 2002a), or by measuring the average journey-to-work commuting time of the census tract where the property is located (Voith 1993). Although attempting to control for regional accessibility is an improvement over prior studies, these studies fail to distinguish between the regional accessibility advantages conveyed by commuter rail and the regional accessibility advantages provided by other transportation modes. This distinction is particularly important when the accessibility benefits of commuter rail differ consistently from those of other transportation modes. As Ryan (1999) points out, the concern is that the regional benefits of a transportation mode should be considered only relative to other modal options available. A second hypothesis for the current study is therefore that commuter rail confers regional accessibility benefits, even after controlling for the regional accessibility benefits provided by other transportation modes such as automobile and ferry boat.

In addition to the conceptual arguments presented before, there are additional practical reasons for considering the local accessibility benefits of commuter rail separate from the regional accessibility benefits. First, examining the local accessibility benefits of commuter rail, net of its regional accessibility benefits, is useful for addressing concerns of stakeholders regarding the perceived impacts of fixed-rail projects at the local level. Isolating the two appears helpful for evaluating project feasibility and clarifying stakeholder perceptions regarding the impacts of commuter rail. Second, estimating the value that people place on local accessibility is critical for determining the potential of commuter rail stations as magnets for land development, as many transportation planners would like. Accordingly, a third hypothesis for this study is that residents of the study area value accessibility to commuter rail stations, net of the proximity-related deleterious effects and other confounding influences.

3. Hedonic model approach

Rosen (1974) formalized the theory underlying the market for heterogeneous goods. Using Rosen's approach, single-family residential properties can be best characterized as complex heterogeneous goods, each consisting of an inseparable bundle of attributes of varying quantities and qualities. The price of a residential property is a function of the levels of the characteristics embodied in the good. These characteristics can include not only structural and site attributes of a property, but also measures of the quality of local services, locational attributes such as accessibility to the CBD, and environmental amenities such as freedom from noise. Although each characteristic is not individually exchanged in an explicit market transaction, implicit prices for these attributes can be inferred by observing individuals' willingness to pay for each unique bundle of characteristics represented by each residential property.

Despite the apparent usefulness of hedonic price functions, their estimation is fraught with uncertainties, including potential omitted variable biases, choice of functional form for the price function, and spatial autocorrelation. The implications discussed previously of omitting commuter rail's proximity-related externalities from the hedonic price function are an example of the omitted variable problem. The functional form problem is often addressed by specifying a flexible price function, although Cassel and Mendelsohn (1985) argue that this may compromise the function's ability to tolerate mis-specifications. In an earlier study Palmquist (1984) chose the linear form from among linear, loglinear, semi-log and inverse semi-log forms. Cropper et al. (1988) found that simple functional forms, such as linear, semi-log, double-log, and linear Box–Cox forms, perform better than more complex ones when variables are missing or mis-measured. As a result, the relationship we investigate is of the general form:

$$Y_i = \alpha + X_i\beta + \varepsilon_i \tag{1}$$

where Y_i is a measure of market value of the ith property; X_i is a vector of measures of k property attributes; β is a vector with the estimated implicit marginal price for each attribute k; α is the intercept term standing for the effect of excluded variables on the value of the property; and ε_i denotes stochastic error terms. Because we have few a priori expectations about the form of the hedonic price function, and based on the evidence reviewed, we estimate three sets of equations. The first is a linear regression where the dependent and independent variables are not transformed. In the second equation we apply a logarithmic transformation to the dependent variable and use the untransformed independent variables. The third equation involves a log-transformed dependent variable and log-transformed independent variables when they are continuous. Although the linear Box–Cox transformation imposes fewer restrictions on the functional form of the hedonic relationship, we focus on the linear, semi-log, and double-log functional forms due to pragmatic reasons related to how we account for the potential problem of spatial autocorrelation.

Spatial autocorrelation due to spatial dependence and unobserved spatial heterogeneity in the observations is another potential problem of hedonic price functions. Depending on the nature of the spatial autocorrelation, it may lead to inefficiency in the ordinary least squares (OLS) estimator or to inconsistency and bias in the estimates of implicit prices. We address this problem by using diagnostic tools to test for misspecification problems of the three functional forms specified, and to determine the appropriateness of models that incorporate spatial dependence explicitly. We achieve this by first using OLS to estimate β by regressing Y_i on X_i. Based on the OLS residuals, Lagrange multiplier tests (see Anselin & Getis 1992) and their robust counterparts (see Anselin et al. 1996) are used in conjunction with several specifications of spatial contiguity as diagnostic tools to test for the two most relevant forms of spatial autocorrelation in applied empirical work: autocorrelation in the form of a spatially lagged dependent variable, and dependence in the regression error term (Anselin et al. 2000). Based on the diagnosis, we apply maximum likelihood methods (Anselin & Bera 1998) to estimate the coefficients while accounting for the spatial dependence in the data, if necessary. This approach is consistent with recent research emphasizing the relevance of testing for spatial dependence in hedonic price functions (Brunsdon et al. 1996; Can & Megbolugbe 1997; Bowen et al. 2001; Fotheringham et al. 2002).

4. Hedonic analysis of commuter rail impacts in Eastern Massachusetts

The MBTA provides commuter rail service in Eastern Massachusetts. Rather than focusing on the entire region, the data collection process for this study began with a dataset of the 186 municipalities in Eastern Massachusetts that included contemporaneous information on various geographic, demographic, social, economic development, housing, education, crime, fiscal, transportation service and environmental characteristics at the municipal level. The study area was then systematically narrowed down to the final selected areas. This process required that data be collected from a variety of public and private organizations, including the U.S. Department of Commerce, the U.S. Bureau of the Census, the U.S. Department of Transportation, and the Central Transportation Planning Staff (CTPS) and several Massachusetts-level state offices such as the Executive Office of Environmental Affairs (EOEA), the Executive Office of Communities and Development (EOCD), the Department of Revenue, Massachusetts Department of Safety, and the Massachusetts Department of Education (for additional details see Armstrong 1997).

Availability of sales price information for individual properties reduced the selection subset to 137 cities and towns, representing 73.7% of all the cities and towns in the Boston metropolitan area. Concern with potential omitted variable biases led us to apply selection criteria such as the absence of potential confounding influences (e.g. limited-access highways nearby, undesirable local land uses, other transit services for accessing Boston, and heavy freight rail traffic on the same right-of-way as commuter rail) which reduced the number of possible municipalities. The criteria were applied in a progressively restrictive process, resulting in the selection of four municipalities with commuter rail service as the study areas: Needham, Norfolk, Acton and Winchester.

It is possible that the mere presence of a commuter rail station in a municipality results in a price premium for properties in it, perhaps because of the way in which residential properties are marketed by real estate firms, or because these stations tend to be located in more traditional urban concentrations having high commercial and employment activity. Thus, we deemed it necessary to expand our dataset by including municipalities that do not have a commuter rail station within their boundaries, but that satisfied conditions regarding the absence of potential confounders. Broad matches with the four commuter rail study areas in terms of municipal characteristics such as AM peak auto travel time to downtown Boston (1992), per pupil expenditure (1993), residential property tax rate (1991), median household income (1989), journey-to-work public transport mode share (1990), population density, and crime rate, among others, resulted in the selection of the towns of Lexington, Hingham, and Boxford as the no-commuter rail study areas. In the aggregate, these additional municipalities are selected to represent generally, but not strictly, similar communities as those selected in the group with commuter rail stations, although the hedonic regression model will control for any observable differences.

Having selected municipalities for the study, the next step in the data collection process was to select individual properties within each of the seven municipalities. Data for individual, single-family detached residential properties in each community were collected for the four quarters of 1992 and the first quarter of 1993. Although this period saw slow increases in property values in metropolitan Boston, between the beginning of the second quarter of 1992 and the beginning of second quarter of 1993 there was little if any change in housing prices (Case & Shiller 1994).

A property's selling price during the selected period, as published by *Banker & Tradesman* (Boston, MA), is used as an indicator of its market value. Prices included are based on sales from $200,000 to $500,000, and property transactions data are differentiated by type of property. Although a cross-sectional analytical approach is used, the real estate sales data utilized are of necessity collected from a time period during which overall real estate market forces are likely to have had an impact on sales prices. Selling price can reflect confounding effects such as seasonal variation in demand, local economic conditions, government regulatory practices, and the availability of financing, among others. By design, the 1992–1993 time frame selected for analysis was chosen to minimize just such temporal market variations as much as possible. However, because of the 15 month time frame, a number of moderate real estate market fluctuations remain in the data. Therefore, variations in sales prices over this time frame were eliminated using housing price indices estimated using repeat sales data and developed independently of our data by the real estate analysis firm of Case Shiller Weiss, Inc. (Cambridge, MA). Sales prices reported in the Banker & Tradesman data were deflated to January 1992 dollars using the Case-Shiller home price index for three price market segments in metropolitan Boston.

The data were subject to a series of quality control procedures to identify and discard records that for various reasons were inadequate for inclusion in the final data set. Refinanced properties, transactions that are not at arms-length, unusually high repeat sales of the same property within periods of less than 2 weeks, and foreclosure deeds, among others, are excluded. The remaining data consist of 1,860 transaction records of single-family detached residential properties within the price range specified sold during the defined period.

4.1. *Measures of local accessibility to commuter rail*

The commuter rail stations in the study area are predominantly accessed by car (park and ride, and kiss and ride) or by walking, with little access by other modes such as local bus service and bicycle (Humphrey 1995). We measure local accessibility as the shortest time path from each individual property to the nearest commuter rail station by foot and by car. All distance-related measurements are determined based upon digital orthophotography (1:5,000 scale) or digital U.S. Geological Survey quadrangles (1:24,000 scale), which were used to augment data from the 1994 U.S. Bureau of the Census TIGER/Line data (1:100,000 scale).

Traffic engineering (Garber & Hoel 2001) and transit planning practice suggests that walking speeds of approximately 3 miles per hour are representative of most pedestrians, and therefore this value is used here. Link speed attributes for local auto travel were developed based on site visits and sample travel time runs. A 5 minute penalty time, representing the time spent parking and waiting at the platform, is added to local access time by auto.

Finally, in addition to walk and auto access time to the commuter rail station, a dummy variable is used whose value equals one when a property is located in a municipality that has at least one commuter rail station. This variable is intended to control for unobserved station-related accessibility benefits that a municipality may accrue, but that are not captured by other variables. Together, these three variables are used to test our hypothesis that residents in the study area value accessibility to commuter rail stations, net of other confounding influences.

4.2. *Measure of commuter rail's regional accessibility*

Regional commuter rail accessibility is measured by scheduled line-haul travel time from each station to its downtown destination (either North Station or South Station). For communities without commuter rail stations within their municipal boundaries, the closest station was identified and used in calculating these times. All four communities with commuter rail stations received comparable train frequencies consisting of five AM peak period trains per day, the only difference being Needham, where two of the five peak period trains are short-turned, providing two stations with only three AM peak period trains daily. Because these service levels are comparable, inclusion of the number of AM peak trains as an independent variable was deemed unnecessary.

4.3. *Other accessibility attributes*

Although the variables described above constitute commuter rail accessibility characteristics for the properties being studied, other accessibility-related variables that are not specific to commuter rail service must also be accounted for in the hedonic price function. These include parking availability and the presence of different types of land uses at each station, access to local highways, and access to the CBD and to the other areas of employment.

To control for the confounding effect of parking availability, we calculated an index of parking convenience for each municipality with a commuter rail station. The index was determined by dividing the total number of parking spaces available at all stations in each municipality by the number of individuals in the labor force in the municipality.

Measurements of the type of land uses around each station were used to control for the potential effects that proximity to these areas might have on property values. We measure the percent of land that is devoted to commercial and industrial uses within a one-quarter mile buffer zone of around each commuter rail station, using digital geographic land use data obtain from the Massachusetts Executive Office of Environmental Affairs. Measures using a one-half mile buffer and measures focusing on commercial land use only were also developed.

Ryan (1999) argues that the accessibility benefits of a transportation mode should be considered relative to other modal options available to individuals, and therefore we control for the relative availability of auto and ferry boat modal options. As a result, we use the same shortest time path routine to estimate driving time from each property to the nearest highway interchange and to the Hingham Shipyard where commuter ferry boat service to Boston's CBD is provided. A 5 minute waiting time is also added to the commuter boat access time. Peak period travel time to downtown Boston via automobile (derived from travel time skims obtained from the Central Transportation Planning Staff (CTPS) of the Boston MPO), and the journey-to-work average travel time reported by the 1990 U.S. Census for the block group where each property is located, were also included to control for regional accessibility via different modes. Work accessibility, which is measured by the journey-to-work trip time, has been used in the past (Helling 1998) as an indicator of overall accessibility, partly because the location of worksites tends to be spatially correlated with the location of other amenities such as recreation and commercial sites.

4.4. *Structural, neighborhood and municipal attributes*

Consistent with the prior literature on hedonic price functions, we control for property attributes that can influence the market value of a property such as lot size, usable living area, number of bedrooms, number of bathrooms, age of structure and architectural style. For neighborhood characteristics, we include population density of the block group in which each property is located. Additionally, because the value of accessibility to transit and commuter rail has been found to vary with income levels (Diamond 1980; Nelson 1992; Gatzlaff & Smith 1993), we include the median household income for a property's block group.

For municipality-level attributes, we include variables on the quality of the education system, municipal property tax rates, and the quality of local police services. For education, we use measures of integrated per-pupil cost and multi-grade level performance on Massachusetts standardized assessment tests (for details see Armstrong 1997). We also control for residential property tax rates in effect for the fiscal year 1992, as reported by the Massachusetts Department of Revenue, and expressed in dollars per $1,000 of assessed valuation. Finally, we use both violent and non-violent crime rates as a proxy for the overall level of safety and personal security experienced in the community and for the quality of local police services.

5. Results

Table 1 contains a description of the variables and summary statistics of the data described above. Three sets of equations – linear, semi-log and double-log – were estimated. For the latter, neither dummy variables nor variables measured in percent terms, such as percent of land use around the station devoted to commercial and industrial uses, are log-transformed.

The hypothesis that there is no spatial dependence in the residuals was rejected at a 99% level of confidence using likelihood ratio tests (see Anselin 1993). In all specifications, diagnostic tests suggested that both a spatial lag and a spatial error model specification were appropriate ways of accounting for the spatial dependence in the residuals. We opted for using a spatial lag model because not doing so may lead to biased estimates, whereas not estimating a spatial error model might lead only to inefficient estimates. The spatial lag model can be expressed as a mixed regressive-spatial autoregressive process, as

$$Y_i = \alpha + \rho W_i Y + X_i \beta + \varepsilon_i \tag{2}$$

where W_i is a 1 by N spatial weights vector defining the contiguity between observation i and all other observations in space, Y is the N by 1 vector of dependent variables, ρ is the spatially autoregressive coefficient, and all other variables are as defined before. The coefficients for the spatial lag model were estimated using maximum likelihood methods and a spatial weight matrix with contiguity defined as the inverse distance between each property and other properties within a 1.5 km band. Several other definitions of contiguity for the spatial weight matrix, including one based on each property's 15-nearest neighbors, an inverse distance function at 2 and 5 km bands, and a different distance decay function (inverse squared distance), were tested but results did not change significantly.

Estimated coefficients are presented in Table 2. The variables for *CRIME* and *MEAP*, and the *COASTTWN* indicator, were not included in the final regression equation due to high levels of multicollinearity with other community attributes. We excluded these variables because they are one of many

Table 1. Summary statistics for areas of study and control areas ($N = 1{,}860$).

Variable	Description	Mean	Std. Dev.	Analysis Unit
Measure of value				
SLPRIC	Adjusted sales price (January 1992 US$, in 1,000s)	291.41	68.38	Parcel
Structural attributes				
ULAREA	Usable living area (sq. feet)	2211.52	774.40	Parcel
BEDS	Number of bedrooms	3.56	0.83	Parcel
BATHS	Total number of bathrooms	2.03	0.59	Parcel
AGE	Age of the house (years)	42.79	34.96	Parcel
AGE100	Variable indicating property age >100 years	5.81%		Parcel
CAPE	Variable indicating Cape Cod-style house	16.02%		Parcel
RANCH	Variable indicating ranch-style house	16.99%		Parcel
CONTMP	Variable indicating contemporary-style house	5.22%		Parcel
STLOTH	Variable indicating other architectural style	12.04%		Parcel
LTSQFT	Lot size (in thousands of square feet)	32.04	46.26	Parcel
Site/Community attributes				
COASTTWN	Variable indicating municipality with beach access	7.37%		Municipality
POPDEN	Block group population density (per square mile, 1990)	2479.63	1874.59	Block group
COM_IND	% land around station in commercial-industrial uses	1.87	3.67	Station
HHINC	Block group median household income ($1,000s, 1989)	69.44	14.55	Block group
PUPIL	Integrated pupil expenditures ($1,000s, 1992)	5.81	0.76	Municipality
MEAP	Weighted student assessment MEAP test results	455.31	28.80	Municipality
CRIME	Crimes per 1,000 population (1991, 1992, & 1993)	16.02	4.83	Municipality
TXRATE	Property tax rate per $1,000 of valuation (1992)	14.01	1.52	Municipality
TRFHVY	Variable indicating location on heavily used street	3.92%		Parcel
TRFMED	Variable indicating location on moderately used street	9.73%		Parcel

Table 1. (Continued).

Variable	Description	Mean	Std. Dev.	Analysis Unit
Local accessibility to commuter rail				
RAIL1	Auto time to nearest rail station (minutes)	9.15	8.47	Parcel
WLK12M	Variable indicating location within 1/2 mile of station	9.25%		Parcel
STATN	Variable indicating location in municipality with commuter rail station	68.66%		Parcel
Regional accessibility by commuter rail				
RAIL2	Scheduled commuter rail travel time from nearest commuter rail station to North/South station (minutes)	33.73	14.41	Parcel
Other accessibility attributes				
AUTO1	Auto time to nearest major highway ramp (minutes)	7.03	4.55	Parcel
BOAT1	Auto time to Hingham Shipyard terminal (minutes)	54.28	18.23	Parcel
PARKING	Parking supply	0.03	0.03	Municipality
AUTO2	Auto time from CTPS zones to CBD (minutes)	42.19	10.76	CTPS traffic zone
JTWTIM	Block group journey-to-work time (minutes, 1990)	24.54	3.70	Block group
Proximity-related commuter rail externalities				
CROWFT	Aerial distance to commuter rail right-of-way (1,000 ft)	12.65	15.70	Parcel

proxies for the same exogenous effect, or because they are not the primary objects of interest for this research. Additionally, the variable measuring walking time to the station was highly collinear with driving time to the station, and therefore we replaced it with a dummy variable indicating whether the property is within one-half mile of the commuter rail station. Overall model fit across specifications is adequate, with the square correlation statistic ranging from 0.582 for the semi-log equation to 0.951 for the double-log equation. The square correlation statistic is a goodness-of-fit statistic measuring the correlation between predicted and observed values (for details see Anselin & Bera 1998). Other measures of goodness of fit such as the ratio of the variance of predicted values over the variance of observed values for the dependent variable also suggest adequate model fit. We also use robust Lagrange Multipliers to examine if residuals exhibit spatial dependence after estimating the spatial lag model (Anselin 1988; Anselin et al. 1996). Results suggest that the lag model is adequate for the linear and semi-log equations, but that the residuals of the double-log model still exhibit some spatial dependence best accounted for with a spatial error model. In practical terms, this means that the estimates of the double-log model are not efficient, but they remain unbiased.

5.1. *Commuter rail accessibility and proximity-related externalities*

Visual inspection of the coefficients for the three local accessibility variables suggests ambiguous results. For the linear and semi-log equations, neither the coefficient for the dummy variable indicating location within a one-half mile distance of a station (*WLK12M*) nor the coefficient for the variable for auto access time to commuter rail (*RAIL1*) are statistically significant. However, the *STATN* dummy variable indicating the presence of one or more stations in each municipality is positive and statistically significant at the 99% level of confidence in these two equations. The linear specification suggests a premium of more than \$29,532 for properties located in the municipalities with one or more commuter rail stations. Evaluated at the mean selling price, this translates into a 10.1% market value premium. The coefficient in the semi-log specification suggests a premium of 9.6%, because $\ln(1+i) = 0.092$, where i is the percentage increase in question. By contrast, the double-log specification shows that *WALK12M* and *RAIL1* are significant (90% and 99% levels of confidence, respectively), but that *STATN* is not significant. The estimate suggests a price elasticity of driving access time of −0.145, which evaluated at the mean sales price and the mean station driving access time suggests that for every additional minute of drive time from the station, property values decrease \$4,620 or 1.6%, all else held equal. Likewise, properties located within a one-half mile radius of a commuter rail station sold for prices that are

Table 2. Spatial hedonic model of property selling price ($N = 1{,}860$).

	Linear		Semi-log		Double-log	
	Coefficients	Std. Error	Coefficients	Std. Error	Coefficients	Std. Error
Rho	0.360***	0.034	0.361***	0.033	0.072***	0.020
constant	−132.097***	30.923	2.575***	0.202	2.524***	0.454
Structural attributes						
ULAREA	0.045***	0.002	0.000***	0.000	0.407***	0.053
BEDS	4.155***	1.570	0.013**	0.005	0.150**	0.060
BATHS	20.160***	2.444	0.066***	0.008	−0.113***	0.027
AGE	−0.080	0.056	0.000*	0.000	−0.082***	0.014
AGE100	5.806	6.767	0.027	0.022	−0.354***	0.057
CAPE	−22.405***	3.186	−0.079***	0.010	0.106***	0.038
RANCH	−19.785***	3.215	−0.070***	0.010	0.049	0.038
CONTMP	11.711**	4.888	0.029*	0.016	−0.204***	0.040
STLOTH	−9.060**	3.770	−0.035***	0.012	1.423***	0.033
LTSQFT	0.223***	0.058	0.001***	0.000	0.008	0.021
LTSQFT_sq	−1.74E − 04*	1.01E − 04	−7.25E−07**	7.33E−06	–	–
Site/Community attributes						
POPDEN	−2.92E−04	9.92E−04	1.20E-09	3.20E−06	0.007**	0.003
COM_IND	−0.183	0.329	−0.001	0.001	0.002	0.003
HHINC	0.406***	0.087	0.001***	0.000	0.297***	0.067
PUPIL	42.275***	3.782	0.135***	0.012	0.027	0.040
TXRATE	−6.492***	1.925	−0.020***	0.006	0.052	0.040
TRFHVY	−26.287***	5.501	−0.087***	0.018	1.06E−05***	2.32E−06
TRFMED	−15.406***	3.659	−0.052***	0.012	1.35E−05***	3.23E−06

Local accessibility to commuter rail						
RAIL1	0.323	0.653	0.000	0.002	−0.145***	0.042
WLK12M	−2.237	4.085	−0.006	0.013	0.096*	0.054
STATN	29.532***	9.263	0.092***	0.030	0.014	0.039
Regional accessibility by commuter rail						
RAIL2	−0.040	0.197	0.000	0.001	0.080***	0.015
Other accessibility attributes						
AUTO1	0.685	0.446	0.002*	0.001	0.039	0.025
BOAT1	−0.644***	0.153	−0.002***	0.000	−0.260***	0.063
PARKING	110.852	108.669	0.320	0.351	−0.160**	0.077
AUTO2	−0.938**	0.460	−0.004**	0.001	−0.087***	0.024
JTWTIM	0.918*	0.487	0.003**	0.002	−0.250***	0.056
Proximity-related commuter rail externalities						
CROWFT	0.732**	0.316	0.003***	0.001	0.126***	0.023
Variance ratio		0.571		0.574		0.951
Square correlation		0.582		0.585		0.951
AIC		19455.3		−1882.93		1959.27
LR test (lag model vs. OLS)		45.59		44.97		12.97
LM test, spatial error dependence		0.673		1.066		50.76
Log likelihood at convergence		−9.697		971.47		−131.258

***, **, and * denote coefficient significantly different from zero at the 1%, 5%, and 10% level of significance (two-tailed test), respectively. Coefficients for dummy variables (in bold) are adjusted for interpretation according to (Kennedy 1981). The weights matrix for the spatial lag model is row-standardized and based on the inverse distance for observations within a 1.5 km. distance band. The variables *CRIME*, *MEAP*, and *COASTTWN* are excluded due to high collinearity with other variables.

10.1% higher than other properties. A test of the significance of the three local accessibility parameters suggests that they are jointly different from zero at a 95% level of confidence. Taken as a whole, therefore, the estimated parameters suggest that the local accessibility benefits of commuter rail are capitalized into the value of the properties examined.

For the regional accessibility benefits of commuter rail, the estimated coefficient for the *RAIL2* variable is not statistically significant at standard levels of confidence in the linear and the semi-log equations. However, in the double-log equation the coefficient has a positive, unexpected sign, suggesting that for every 10% higher travel time, properties have a 0.8% higher value. Taken together, our results for this variable suggest that our expectations regarding the regional accessibility benefits of commuter rail, even after controlling for the regional accessibility benefits provided by other transportation modes such as automobile and ferry boat, are not realized.

Overall, the commuter rail accessibility results suggest that the presence of a station is associated with higher residential property values throughout a municipality, after controlling for local access time to the station. Depending on the model specification, the results show that the presence of a station appears to be valued at the municipal level, or that properties with better local access to commuter rail by virtue of being located in a municipality with a station have higher prices. It is possible that the coefficient for the municipality variable may be capturing unobserved characteristics of the community, or the way in which residential properties are marketed by real estate firms. More broadly, however, the empirical evidence regarding the capitalization of commuter rail's local accessibility benefits presented here is somewhat limited. This reinforces expectations about commuter rail's limited potential as a catalyst for inducing transit-related land developments.

Consistent with our hypothesis that the negative effects related to proximity to the right-of-way are particularly important for properly quantifying the accessibility benefits of commuter rail service, the estimated coefficient for the variable representing commuter rail's proximity-related externalities (*CROWFT*) is positive and statistically significant at levels of confidence ranging from 97% (linear) to 99% (semi-log and double-log). The coefficient estimated from the linear model suggests that for every 1,000 ft. in distance from the commuter rail right-of-way, property values are $732 higher, all else held equal. Evaluated at the mean distance to the right-of-way (see Table 1), the estimated effect translates into an elasticity of between 0.03 (linear model) and 0.13 (double-log model).

It is likely that these coefficients overestimate the true effect of proximity, partly because freight rail service also operated to varying degrees over most of the rights-of-way analyzed here during the study period. Although the service frequency of freight trains is considerably lower than commuter rail trains, it is reasonable to expect that their length and their possible operation during nighttime hours—affecting the relative nuisance effect from their noise—will result in steeper price discounts for freight rail than for a similar commuter rail train operation. Thus, the confounding effect of freight and commuter rail service is a question that further research should investigate. Nonetheless, because commuter rail service often comes bundled with freight service, these results should be interpreted as empirical evidence of the joint contribution of the proximity-related impacts of commuter rail and freight service regarding property values.

An implicit assumption in the specification of the accessibility variables and proximity-related distance variable is that distance or time influences the dependent variable linearly. For these variables, however, it may be less restrictive to allow for the possibility of non-linear effects on property price. We tested this assumption by including in the linear and semi-log equations a second and third order polynomial term for auto travel time to the commuter rail station and for the distance-to-the-right-of-way measure. Results for these terms (not shown) were not statistically significant, and therefore our initial assumption was correct.

5.2. *Other relevant impacts*

While our interest lies with the impacts of commuter rail service, reasonable results with respect to other variables lend credence to the analysis. The non-rail regional accessibility variables (*AUTO2* and *JTWTIM*) are significant in all three models. As expected, higher auto commuting time to downtown is associated with lower property prices. By contrast, our results for the average trip time to work in the neighborhood are equivocal. For the linear and semi-log equations the coefficient is positive and significant, but for the double-log equation it becomes negative and remains significant. The latter conforms to expectations that property values should decrease with increasing driving time.

For local accessibility to other transportation modes, the coefficients estimated in the three equations suggest that as travel time to the Hingham Shipyard increases, property values decrease (99% level of confidence). The elasticity estimates range from −0.112 (semi-log, evaluated at the variables' means) to −0.26 (double-log model). By contrast, the coefficient for local interstate highway access is significant for the three models at the indicated level of confidence (87%, 91% and 88% level of confidence for linear, semi-log and double-log, respectively), but with an unexpected sign. The sign suggests that as the distance to the closest highway interchange increases, property values increase. We estimate that a 1 minute increase in travel time is associated with between a 0.9% (semi-log) and a 5.5% (double-log) higher selling price. At the mean access time and property values summarized in Table 1, the estimated effect translates into an elasticity of between 0.002 (linear) and 0.039 (double-log). This may be the result of (unobserved) negative externalities associated with highway infrastructure, such as noise, visual intrusion, vehicular emissions, and traffic congestion. Finally, coefficients for structural attributes tend to have the expected signs, with more living area and a greater number of bedrooms increasing house values. Coefficients for variables measuring location on streets with heavy and medium vehicular traffic have the expected negative signs and exhibit statistically significant coefficients (99% level of confidence) in the three equations estimated. The results for the linear and semi-log equations suggest traffic-related discounts of about 8.3% to 9% of the value of the property when it is located on a heavy traffic street, and 5% when the property is located on a medium traffic street, relative to properties located in low traffic areas.

6. Conclusions

This study has examined the impact of commuter rail service upon communities in metropolitan Boston using single-family residential properties, evaluating the beneficial impacts arising from increased local and regional accessibility and the deleterious impacts arising from proximity to commuter rail facilities. Overall, we find some evidence that the accessibility benefits of commuter rail are capitalized into single-family residential property values. Using a linear and semi-log model specification, we fail to detect statistically significant associations between property values and measures of local accessibility to commuter rail stations by automobile and pedestrian modes, but we succeed in doing so using a double-log specification. The latter indicates that properties located within a one-half mile buffer of a commuter rail station exhibit values that are 10.1% higher than properties located outside of this buffer area and that for every additional minute of drive time from the station, property values decrease by 1.6%, all else held equal. Our third measure of local accessibility in the linear and semi-log models suggests that properties located in municipalities with commuter rail stations exhibit values that are between 9.6% and 10.1% higher than those located in municipalities without commuter rail, all else held equal. We attribute this premium to either the presence of a commuter rail station, or ancillary (unobserved) characteristics of a community related to the presence of the station. A joint test of significance of the three variables suggests that they are different from zero at various confidence levels that exceed 95%. As such, we conclude that the properties in our sample exhibit some capitalization of the local accessibility benefits of commuter rail.

The data also were able to discriminate between the benefits of access to a commuter rail station, and the nuisance effects such as proximity to the right-of-way. A 1% increase in distance from the right-of-way is associated with property value premiums that range from 0.03% to 0.13%, which can be translated into a range from \$73.21 to \$289.72 per house for every additional 100 ft. from the right-of-way, at the mean selling price. This suggests that accounting for proximity-related deleterious effects of commuter rail is key for understanding its impacts on property values. Likewise, discounts of between 5% and 9% were detected for properties located on streets with medium and heavy vehicular traffic, respectively.

The view that the accessibility benefits provided by transit will translate into land development changes has resonated increasingly with urban planners under the rubric of transit-oriented developments. However, to the extent that our results can be generalized, they validate concerns about the effectiveness of commuter rail service as a catalyst for such developments because the accessibility benefits it provides seem to be weakly reflected in property values. Such willingness to pay for improved access is pivotal to the land development impacts of transportation projects. Our findings, however, are not entirely surprising given the orientation of commuter rail service towards bedroom community dwellers, with lines often extending well beyond the immediate urban area into lower density suburbs, sometimes 30–50 miles from central city terminals.

While discussions about the distributional implications of the benefits and costs of commuter rail service relative to other transportation investments should remain a priority for decision-makers, this study provides useful information for the planning and evaluation of new or expanded commuter rail facilities. With potential expansions of commuter rail service being planned in the future, issues related to both its beneficial and deleterious impacts may become a growing concern to both the affected public and to transit planners. This study provides localized evidence of the accessibility and proximity-related impacts of such service.

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