Urban Studies
48(1) 101–127, January 2011

The Impact of Transit-oriented Development on Housing Prices in San Diego, CA

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[Paper first received, December 2008; in final form, September 2009]

Abstract

This research measures the influence of transit-oriented development (TOD) on the San Diego, CA, condominium market. Many view TOD as a key element in creating a less auto dependent and more sustainable transport system. Price premiums indicate a potential for a market-driven expansion of TOD inventory. A hedonic price model is estimated to isolate statistically the effect of TOD. This includes interaction terms between station distance and various measures of pedestrian orientation. The resulting model shows that station proximity has a significantly stronger impact when coupled with a pedestrian-oriented environment. Conversely, station area condominiums in more auto-oriented environments may sell at a discount. This indicates that TOD has a synergistic value greater than the sum of its parts. It also implies a healthy demand for more TOD housing in San Diego.

Introduction

This research presents a statistical analysis of the housing price premium associated with transit-oriented development (TOD) in San Diego, CA. While precise definitions of TOD will vary, it generally refers to walkable, compact and mixed use development adjacent to a transit station (TCRP, 2004). Previous studies have shown that property near rail stations often sells at a modest premium (Debrezion *et al*., 2007; Hess and Almeida, 2007). The subsequent analysis builds upon such studies by illustrating how station area premiums can be enlarged when combined with a complementary built environment (i.e. TOD).

The synergistic combination of good transit and good pedestrian access inherent in TOD has the potential to provide a comprehensive alternative to the automobile (Bernick and Cervero, 1997). Transport planners often promote TOD as a way to reduce driving

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0042-0980 Print/1360-063X Online

DOI: 10.1177/0042098009359958

and redress auto-related problems such as congestion, emissions, energy consumption, inequality of access and sprawl (Cervero *et al.*, 2002). However, the ability of TOD actually to ameliorate these problems remains open for debate (Boarnet and Crane, 2001; Steiner, 1995). It is still unclear how much TOD actually affects travel behaviour and whether enough TOD can be built to create an aggregate impact of significance.

In regard to the efficacy of TOD in reducing an individual's auto use, a large body of work has examined the influence of urban form or rail proximity on travel behaviour (TRB and IOM, 2005; Ewing and Cervero, 2001; Crane, 2000; TRCP, 1996) and a subset of this research focuses specifically on TOD (Arrington and Cervero, 2008; Cervero, 2007; Lund, 2006). The findings often demonstrate a negative correlation between auto use and various components of TOD, but residential self-selection complicates causal inferences. In other words, existing preferences for walking, biking and transit may lead people to choose housing in places that can accommodate such travel preferences (Schwanen and Mokhtarian, 2004). This makes it difficult to separate the direct impact of the built environment from the pre-existing preferences of those who live in a given neighbourhood type. Recent work has used longitudinal research designs that control more effectively for self-selection and these studies continue to show a significant relationship between the built environment and travel, although the strength of this relationship remains an open question (Mokhtarian and Cao, 2008). While not the focus of this paper, validating the efficacy of TOD requires more in-depth research that is specifically focused on TOD and travel behaviour.

Assuming that TOD does lead to significant individual reductions in auto use, a commensurate aggregate reduction would require a much greater quantity of TOD than currently exists in most, if not all, US regions (TCRP, 2004; Downs, 1994). This would first require the removal of regulatory constraints that prohibit mixed-use and high-density development and, therefore, impede the construction of TOD (Levine, 2005; Boarnet and Crane, 1998). It also requires that ample developable land or property with potential for redevelopment be available near stations.

Independent of supply constraints, TOD expansion will also depend on a healthy demand for such development. Price premiums provide a good indicator of demand *vis-à-vis* a given level of supply. Thus, a broad objective for the subsequently presented price model lies in assessing the demand-side potential for TOD housing expansion[1] in a predominantly auto-oriented region such as San Diego.

Theoretical and Empirical Background

Location Theory

The idea that TOD or other transport improvements can raise property values relies upon the theoretical framework provided by location theory (Alonso, 1964; Muth, 1969). A highly accessible location provides travel cost savings and this should translate to more competition and higher property values. Bids will theoretically increase until the travel cost savings become fully capitalised into the price of the property.

Some question the applicability of location theory in modern cities, especially with regard to non-auto modes (Giuliano, 2004). Most regions in the US already have a well-connected, auto-based transport network accompanied by a spatial dispersion of both housing and commercial activity (White, 1999). This translates to a high minimum standard for accessibility and lessens competition for the most accessible locations. The dispersed development also limits the effectiveness of non-auto modes and reinforces an already strong general preference for auto travel (Hemily, 2004; Pucher and Renne, 2003).

Despite the broader trends, even auto-oriented cities will have at least a niche market for locations with good transit and pedestrian access. Those that have a physical impediment to driving or an economic impediment to auto ownership[2] make up key segments of this market (Black, 1995). Others might want to live in TOD more out of preference than necessity (TCRP, 2008; Krizek, 2006; Schwanen and Mokhtarian, 2004). This group might include those looking for a vibrant urban milieu or an active lifestyle. Further, those with ideological concerns about the environment and energy dependence are likely to put greater value on locations that reduce the need for driving. The sum of these various population segments is not likely to form a dominant share of a given region's housing market. However, these groups may still prove large enough to fuel TOD price premiums, especially given the small and probably undersupplied inventory of TOD (Levine and Frank, 2007; Levine, 2005).

Previous Empirical Findings

Motivated by the need to evaluate the surge of rail transit investment in the late 20th century (Kahn, 2007), much research has focused on the property value impacts of rail systems. At least 50 studies have emerged on this topic since the 1970s (Hess and Almeida, 2007; Cervero, 1997), although comparing and making generalisations about the research presents difficulties because the methodology, geography and temporal context vary greatly. Based on several published reviews of transit capitalisation literature, one might safely generalise that single-family properties near stations sell at small to modest premiums of up to 10 per cent (Hess and Almeida, 2007; Ryan, 1999; Cervero, 1997; Huang, 1996; Vessali, 1996; Landis *et al.*, 1995). A few studies have focused on other housing types (Cervero and Duncan, 2002a; Damm *et al.*, 1980) and commercial property (Cervero and Duncan, 2002b; Weinberger, 2001). The limited evidence shows that these properties gain as much or more from station access as do single-family properties. Only a few studies (of any property type) show very large (Dewees, 1976) or insignificant premiums (Ryan, 2005; Gatzlaff and Smith, 1993).

These transit capitalisation studies generally implement a research design that assumes station proximity has a price effect independent of other factors. As a result, they produce a single premium finding that applies to the entire study area (for example, being a quarter-mile from any station adds $5000 to the price of a home). While this may give an accurate measure of the average station area premium, it misses potentially large amounts of regional variation in premium size (Huang, 1996). Hence, the existing literature does not distinguish between the price premium generated by station areas with or without TOD.

Some have partially assessed the conditional nature of station area premiums by analysing geographically defined sub-markets (Hess and Almeida, 2007; McMillan and McDonald, 2004; Gatzlaff and Smith, 1993; Nelson, 1992). While looking at such sub-markets does illustrate spatial variation in transit capitalisation benefits, the researcher can only theorise about what drives this variation. Bowes and Ihlanfeldt (2001) have taken another step forward in this regard by statistically testing the interaction between station proximity and specific station area attributes. They found that variables such as station parking, CBD distance and neighbourhood income significantly influence the way that station proximity affects home prices in Atlanta. This type of research design provides important and actionable information for determining station locations and planning station areas.

Research Design

TOD and the Conditionality Station Area Premiums

This research seeks to build on the transit capitalisation literature and, in particular, the work of Bowes and Ihlanfeldt (2001) by further exploring the conditionality of station area premiums. More specifically, this work looks at how TOD characteristics (for example, a well connected street pattern, attractive commercial destinations mixed with housing, and flat walking paths) condition these premiums. The following paragraphs will explore theoretical reasons for this conditional relationship.

Good pedestrian links to stations represent the most practical reason that TOD should enhance the value of rail proximity. Pedestrian-friendly development patterns make reaching a station easy, pleasant and interesting (Givoni and Rietveld, 2007; Kim *et al.*, 2007). Having such pedestrian links increases the level of accessibility provided by a rail system. In turn, this should increase the value of station-proximate locations.

The transit and pedestrian components of TOD have a broader synergy that goes beyond simply enhancing station linkages. This synergy is likely to relate to having good access to both work and non-work activities without needing an automobile. Living near a rail station is likely to serve well as a non-auto option for work-related travel, particularly for those who work in the CBD and other job centres along a rail line (Pucher and Renne, 2003). However, taken alone, the rail system may not provide access to the various locations a person needs or wishes to frequent for non-work activities. Conversely, living in or near a pedestrian-oriented commercial district provides many opportunities for conducting non-work activities by walking or biking, but such a district may not contain employment opportunities that match one's occupational skills.

The combination of good rail and pedestrian access provides a more complete auto alternative. For those without access to an auto or who voluntarily try to minimise their auto use, the presence of a rail station should enhance the value of a good pedestrian environment and vice versa.

Research Hypothesis

This research seeks to measure empirically whether TOD has a value greater than the sum of its components (i.e. station proximity and a good pedestrian environment). This requires more than simply testing whether TOD has higher prices than transit-adjacent development (TAD) (i.e. development occurring adjacent to a transit station that does not have the good pedestrian environment found in a TOD). The amenity of a good pedestrian environment may drive up the price of TOD independent of station access (Bae, 2002). In fact, recent research has indicated that 'new urbanist' development has its own premium value (Song and Knaap, 2003; Eppli and Tu, 1999). Thus, a direct comparison of TOD and TAD prices proves little about the synergy between rail and pedestrian access. Instead, this analysis will compare the relative value of TOD and TAD as measured against property with similar pedestrian environments but outside the influence of a rail station. More formally, this research tests the following hypothesis

> Proximity to a rail station adds more to the value of a property in a good pedestrian environment than it does to a property in a bad pedestrian environment.

This hypothesis can also be restated as follows

> A good pedestrian environment adds more to the value of a property in close proximity to a rail station than it does to a property not near a station.

Study Area

The San Diego–Carlsbad–San Marcos, California, metropolitan statistical area (MSA) served as the study area for this research. This region sits in the south-west corner of the continental US. Current census estimates put the MSA's population at 3.1 million. As the region had only 500 000 people at the 1950 census, most development has occurred after the automobile became dominant and generally follows an auto-oriented pattern.

The region's transit system includes the San Diego Trolley. This light rail system began service in the early 1980s with 18 stations along a 21-kilometre corridor.[3] The system has had several stages of expansion and now includes 53 stations along 3 corridors totalling 80 kilometres. It has 7.5- to 15-minute peak hour headways and has a relatively high patronage of over 100 000 daily trips.[4] The region also has a much less extensive commuter rail line (the Coaster) with six additional stations. However, this analysis focuses on the impact of the Trolley. Figure 1 presents a map of the study area and the Trolley system.

The Trolley served well for the purposes of this analysis. The San Diego region and various municipal entities within it have been relatively active in promoting and zoning for TOD (Wilbur Smith Associates, 2006; Boarnet and Compin, 1999; Bragado, 1999). Consequently, the Trolley station areas do contain various examples of TOD. At the same time, several stations have little development other than a park-and-ride facility. Testing for interactions between rail proximity and TOD patterns requires this range of station area environments.

Method of Analysis

This research makes use of a cross-sectional hedonic price model to isolate statistically the price impact of TOD (Rosen, 1974). The model predicts the sales price of condominium units based on rail proximity, measures of the pedestrian environment, interactions between rail proximity and the pedestrian environment, and an additional set of control variables. By measuring the way that the built environment conditions the impact of rail proximity (and vice-versa), the interaction terms provide the key to testing statistically the hypothesis defined earlier.

This research specifically focuses on condo sales because they represent the type of medium- to high-density housing one would expect to find in TOD (Bernick and Cervero, 1997).[5] Modelling condominiums presents a statistical challenge because multiple condo units are grouped into a single structure and multiple structures are commonly grouped into one land parcel. This analysis makes use of 3374 sales of individual condo units, but these units are located on only 439 parcels, so there obviously exists some clustering in the model database. A group of units that cluster in the same parcel are likely to provide a similar bundle of housing attributes and, thus, have similar prices. This violates the assumption of independent observations required for unbiased ordinary least squares (OLS) regression. Consequently, a multilevel model was used instead of OLS (Raudenbush and Bryk, 2001).[6] This model estimation includes a random intercept for each parcel in the analysis and effectively accounts for intraparcel dependence.[7] Additionally, 'robust clustered' standard error estimates were used to prevent the inflated statistical significance commonly associated with clustered data (Moulton, 1990).[8]

It requires mention that the cross-sectional nature of this analysis prevents statistical inference about causality (Singleton and Straits, 1999). Data limitations prevented a more optimal research design that measured prices before and after the introduction of rail stations and before and after any changes in the built environment.[9] Therefore, a cross-sectional model proved the most reasonable,

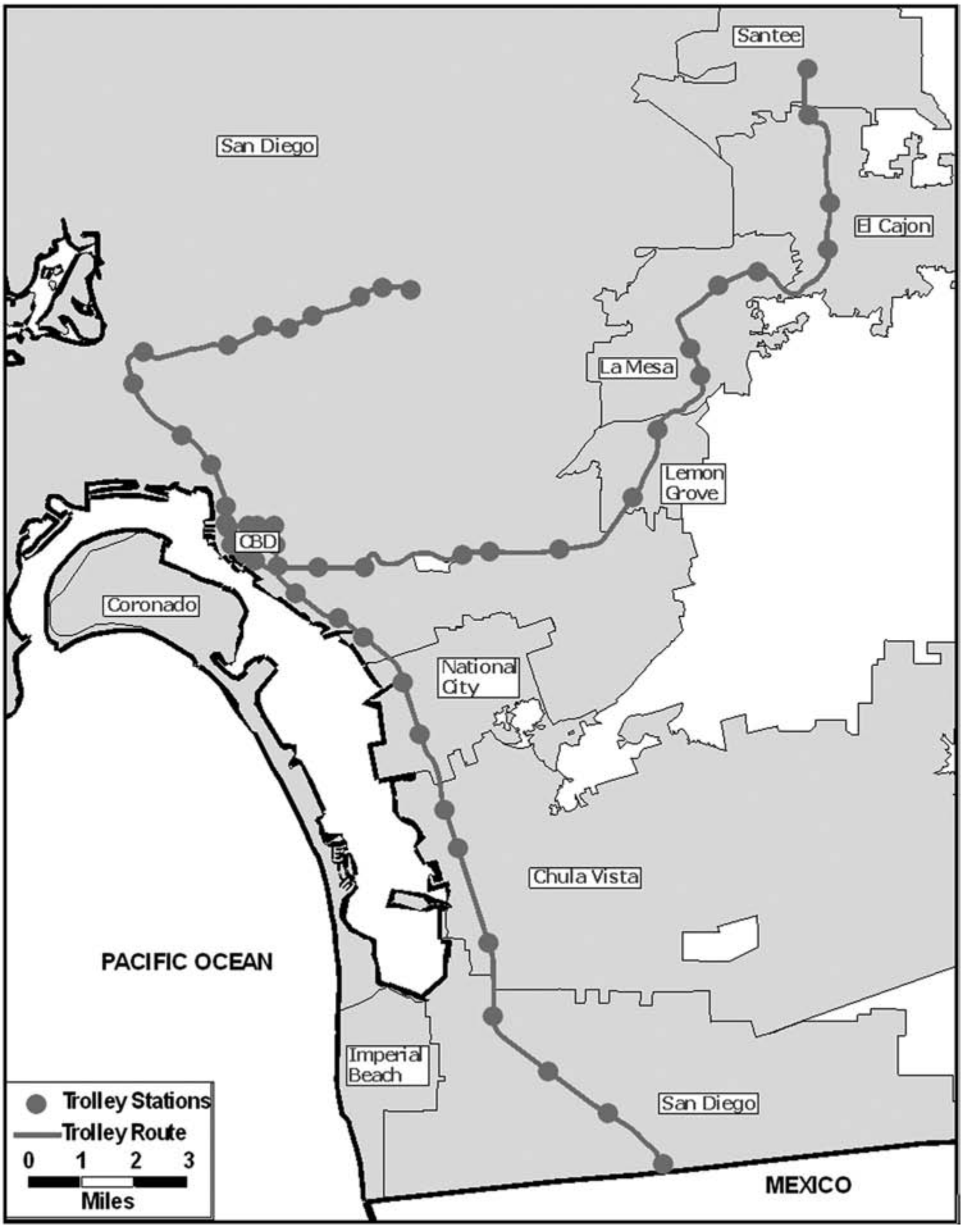

Figure 1. The trolley system.

albeit sub-optimal, approach to testing the research hypothesis.

Selection of Observations

The sales prices used as the dependent variable in this analysis come from a commercial property database.[10] The acquired database provides records for nearly all parcels in the San Diego MSA, including the most recent sales transaction that occurred before 2002. Condominium units used in the price model met the following set of criteria

- The sales transaction must have occurred at arm's length.[11]
- The sales transactions must have occurred after 1996. This ensures some temporal congruence with the data sources of other model variables (the land use and census variables are based on data from 2000), while allowing for five years' worth of transactions (1997–2001).[12] All prices were adjusted to 2000 constant dollars based on the San Diego MSA quarterly housing price index provided by the US Office of Federal Housing Enterprise Oversight. This index is based on actual home prices within the region and should control for inflation, interest rates, seasonal effects, general economic health and other factors that cause fluctuations in the housing market.[13]
- The parcel must fall within 1.6 network kilometres (1 mile) of the nearest Trolley station. Exploratory analysis indicated that the price impact quickly attenuates beyond this distance. This does not necessarily indicate a lack of demand for living at longer distances and driving (or getting a ride) to a rail station. Rather, it probably reflects the exponential expansion of housing supply when moving beyond the immediate station vicinity. Limiting the study area's spatial extent has the benefit of making it more homogeneous, which simplifies the model specification and is likely to lead to a more accurate model (Bourassa *et al.*, 2003; Goodman and Thibodeau, 1998).
- The parcel must fall outside the immediate vicinity of the San Diego CBD.[14] Observations that did not meet this criterion were dropped because their inclusion greatly reduced the size and significance of the rail proximity coefficient and the associated interaction terms.[15] The instability caused by these relatively few observations (473 out of 3847) may stem from two factors. First, CBD condos have very high prices (average of \$306 000 as compared with \$134 000 for non-CBD condos) and a large amount of price variation (standard deviation of \$219 000 as compared with \$59 000 for non-CBD condos). This gives them a disproportionate influence on the estimation of model parameters. Secondly, one of the biggest benefits of living near a Trolley station is that it provides good access to the CBD at a low cost (i.e. no parking charges). Consequently, for those who live within an easy walk of the CBD, the benefits of the Trolley can become superfluous. As CBD condos represent a limited and unique segment of the condo market, their exclusion does not severely limit the usefulness of this research.

After applying these criteria to the database, 3374 complete condominium records remained for model estimation.

Variable Specification

The hedonic price model made use of the following

$$P = f(\mathbf{U}, \mathbf{N}, \mathbf{T}, \mathbf{N}^{*}\mathbf{T}, \mathbf{F}) \qquad (1)$$

Where, P is the sales price of a condominium, which is a function of the following vectors: **U**, unit-specific characteristics; **N**, characteristics of the neighbourhood surrounding the parcel (the neighbourhood is generally defined as a 400-metre radius around the parcel;[16] this vector includes measures of pedestrian quality, which will subsequently be discussed in more detail); **T**, proximity to the nearest Trolley station; **N*T**, interactions between measures of pedestrian orientation and station proximity; and **F**, zonal fixed effects (30 zones based on station catchments).[17]

Table 1 describes the individual variables that make up each of these model vectors. Table 2 lists the corresponding summary statistics and Table 3 provides a correlation matrix of model variables. Table 3 includes

Table 1. Variable descriptions

Variable	*Description*	*Data source*
Dependent variable		
price	Amount (US$) for which the property was sold; dollar values are 2000 (1st quarter) constant	Metroscan
*Unit characteristics (vector **U**)*		
sq_m	Square metres of floor space in the unit	Metroscan
age	Age of the structure (2001–year of construction)	Metroscan
bath	Number of bathrooms in the unit	Metroscan
bed	Number of bedrooms in the unit	
garage	Number of garage spaces attached or assigned to a unit	Metroscan
view	Unit has a view (0–1)	Metroscan
*Neighbourhood characterisics (vector **N**)*		
intsctn	Number of street intersections per hectare within a 400-metre radius of a parcel	SanGIS 2002 road network[a]
ps_jobs	People-serving jobs per hectare within a 400-metre radius of a parcel; this is an aggregation of the following employment categories: food occupation/entertainment industry, entertainment occupation/entertainment industry, sales occupation/retail industry, service occupation/service industry	2000 US Census (by block group)
slope	Percentage slope (rise/run) between the parcel and the nearest Trolley station	SANDAG 10-metre elevation grid[b]
parking	Hectares of land within a 400-metre radius of a parcel dedicated to a park-and-ride lot	SANDAG 2000 land use layer
hwy50m	Parcel is within 50 metres of a grade-separated highway	SanGIS 2002 road network
*Trolley proximity (vector **T**)*		
station	Network kilometres to the nearest Trolley station	MTS rail station GIS layer[c] SanGIS 2002 road network[d]
*Fixed effects (vector **F**)*		
Multiple dummy variables	Series of 30 dummy variables representing station catchment areas; catchment assignment is based on the nearest station to a parcel	MTS rail station layer SanGIS 2002 road network

[a] SanGIS is a GIS repository sponsored by the city and county of San Diego.
[b] SANDAG (San Diego Association of Governments) is the region's metropolitan planning organisation.
[c] MTS (Metropolitan Transit System) is San Diego's regional transit provider.
[d] Various station pedestrian connections were manually added to this street network based on field inspections.

all variable transformations and interactions as they occur in the model. In the interest of a cleaner presentation, the 30 individual dummy variables that make up the zonal fixed effects are excluded from the subsequently presented tables.

Table 2. Variable summary statistics

Variable	*Mean*	*S.D.*	*Minimum*	*Maximum*
Dependent variable				
price	134 136.70	58 842.25	34 792.34	544 302.40
*Unit characteristics (vector **U**)*				
sq_m	91.87	27.62	36.42	262.17
age	20.15	7.68	0.00	71.00
bath	1.66	0.55	1.00	3.50
bed	1.92	0.77	0.00	4.00
garage	0.58	0.79	0.00	2.00
view	0.12	–	–	–
*Neighbourhood characterisics (vector **N**)*				
intrsctn	0.40	0.29	0.05	1.34
ps_jobs	3.38	3.16	0.00	12.35
slope	1.37	1.34	0.00	7.65
parking	0.09	0.32	0.00	2.20
hwy50m	0.05	–	–	–
*Trolley proximity (vector **T**)*				
station	0.98	0.37	0.08	1.60

The zonal fixed effects control for localised variation in prices unexplained by the model's other variables. Because these zones are relatively compact (between 0.5 and 4 square kilometres), they are very homogeneous with respect to some key variables. Hence, the inclusion of these zonal effects eliminates the need to specify several variables that would otherwise need to be included in the model. For example, the zonal effects made the following variables unnecessary and/or insignificant: school quality, municipal characteristics, regional job accessibility and proximity to regionally important locations (such as the CBD, beaches and the Mexican border).

Some additional variables formed part of an initial specification but were dropped because of insignificance. These include: parcel area, the parcel area per unit, proximity to the rail tracks (as opposed to the rail station),[18] proximity to bus routes, proximity to a freeway ramp, housing unit density and neighbourhood income.[19] Although these variables have a more fine-grained spatial variation than those discussed in the previous paragraph, their insignificance may still partially result from zonal effects capturing their variation.

In addition to interacting station proximity with attributes of the surrounding neighbourhood, station proximity was also initially interacted with variables that measured access to jobs and other commercial activity via the rail system. This was done under the assumption that proximity to a well-positioned station (that is, a station with short travel times to important destinations) would provide greater value than proximity to a more isolated one (Allen *et al.*, 1986; Bajic, 1983). However, these interactions did not have statistical significance. This does not necessarily indicate that the level of access has no importance but, rather, that most of the Trolley stations provide some minimum standard of accessibility.

In terms of functional form, the presented model makes use of an untransformed dependent variable. Generally, there is no theoretical basis for choosing a functional form (Cassel and Mendelsohn, 1985; Rosen, 1974). Most hedonic analyses make use of an untransformed

Table 3. Simple correlation matrix of model variables (interactions are mean-centred)

	price	ln (*sq_m*)	*age*	*age2*	*bath*	*bed*	*garage*	*view*	*intrsctn*	*ps_jobs*	*slope*	*parking*	*hwy 50m*	ln (*station*)	*intrsctn* ln(station)*	*ps_jobs* ln(station)*	*slope* ln(station)*
price	1.00																
ln(sq_m)	0.71	1.00															
age	−0.51	−0.28	1.00														
age2	−0.41	−0.21	0.93	1.00													
bath	0.67	0.78	−0.46	−0.38	1.00												
bed	0.50	0.82	−0.21	−0.13	0.67	1.00											
garage	0.56	0.51	−0.46	−0.38	0.51	0.38	1.00										
view	0.26	0.11	−0.04	−0.04	0.13	0.05	0.12	1.00									
intrsctn	0.08	0.15	−0.03	−0.02	0.19	0.18	0.26	0.25	1.00								
ps_jobs	0.32	0.09	−0.23	−0.16	0.11	−0.13	0.05	0.02	−0.33	1.00							
slope	0.09	0.01	0.13	0.08	0.06	−0.05	−0.01	0.23	0.16	−0.44	1.00						
parking	−0.15	0.07	0.18	0.19	0.02	0.06	0.00	−0.07	0.00	−0.11	−0.04	1.00					
hwy50m	−0.13	−0.07	0.03	0.03	−0.06	0.02	−0.09	−0.05	−0.10	−0.19	0.07	0.09	1.00				
ln(station)	−0.04	0.00	−0.02	−0.05	0.06	0.01	0.06	0.10	0.17	−0.12	0.12	−0.36	0.02	1.00			
intrsctn ln(station)*	−0.03	−0.12	−0.06	−0.07	−0.06	−0.01	−0.04	−0.02	−0.11	0.06	−0.04	−0.17	−0.11	−0.08	1.00		
ps_jobs ln(station)*	−0.27	−0.05	0.33	0.24	−0.19	−0.06	−0.13	0.03	0.05	−0.26	0.04	0.20	0.02	0.16	−0.39	1.00	
slope ln(station)*	0.02	−0.05	0.04	0.05	−0.06	−0.04	0.02	−0.04	−0.05	0.07	−0.05	0.21	0.14	−0.29	0.08	−0.20	1.00

or a logarithmically transformed dependent variable. It seems unlikely that the price impact of TOD would increase proportionally with the underlying value of the property as would be the assumption with a log transformation.[20] However, a log transformation has some attractive properties that have caused many researchers to choose this specification (Malpezzi, 2002). Both functional forms were tested and they produced similar results (i.e. coefficients with the same signs and roughly equivalent significance levels). As the untransformed price variable seemed more theoretically appropriate (as described earlier), it was chosen for the final model.

The independent variables were left untransformed except for a few cases where there was a compelling reason to consider a non-linear relationship with condo prices

— The floor space variable was logarithmically transformed. Certain property characteristics may have diminishing returns (for example, each additional square foot of floor space adds less to a condo's value). A logarithmic transformation can capture this effect and applying such a transformation to the floor space variable greatly increased the significance of this variable and improved the overall model fit.
— A quadratic function was applied to structure age. Housing prices generally decline with age but, at a certain point, the charm of older buildings can boost values (all other things equal). A quadratic function effectively captures this U-shaped relationship. Applying this transformation also improved the overall model fit.
— Distance to a Trolley station was logarithmically transformed. This was done to represent the theoretical flattening of the price gradient when moving beyond easy walking distance of a station. Linear and inverse functions were also tested, but the log transformation proved the most significant.

Measuring Transit-oriented Development Patterns

The previous theoretical discussion has relied on a conceptually simple and discrete definition of TOD. However, in reality, any such definition of TOD would prove arbitrary. Some researchers have developed rigorously defined TOD typologies that seek to capture the varying quality and functions of station areas (Schlossberg and Brown, 2004; Dittmar and Poticha, 2003). However, while very useful from a conceptual perspective, these typologies still rely on arbitrary groupings. A good TOD will have various pedestrian components, each with its own independent measurement scale (Saelens and Handy, 2008). Even the most rigorously defined typology cannot create homogeneous groupings for all of the relevant characteristics. Consequently, this analysis will make use of continuous variables representing key aspects of a good pedestrian environment. This approach has the advantage of not imposing an arbitrary boundary on what is and is not a good pedestrian environment. Further, the approach allows a determination of which characteristics interact most strongly with station proximity. The variables representing the pedestrian environment in this analysis include

— *The density of street intersections*: this serves as a proxy for connectivity of the street network and, more generally, the ease with which one can navigate a neighbourhood on foot (Frank *et al.*, 2008).
— *The density of population serving employment* (Ewing *et al.*, 2003): this variable measures an aggregation of employment in entertainment, food, retail sales and service occupations. It represents the amount of non-work activities within a walkable distance of a parcel (Boarnet *et al.*, 2008; Mouden *et al.*, 2006). Many other variables that measure the amount and mixture of commercial/employment activity were tested but the aggregation

of population serving employment (as defined here) interacted most strongly with station proximity.[21]

- *Steepness of the terrain*: this provides a key measure of pedestrian comfort (Cervero and Duncan, 2003). Although frequently ignored, this can prove critical to pedestrian activities in hilly places such as San Diego and San Francisco. The variable measures the slope between the parcel and nearest Trolley station. While this variable specifically measures ease of walking to a station, it also stands as a general proxy for the steepness of terrain surrounding a parcel.[22]
- *Area dedicated to park-and-ride lots*: while this variable has not frequently appeared in studies measuring pedestrian behaviour, it has particular relevance here because rail stations often have large parking lots. Such lots can generate vehicle conflicts that degrade pedestrian links to stations (Kim *et al.*, 2007). Unlike the previously described pedestrian measures, this parking measure was not interacted with station distance. Because these park-and-ride lots always occur very near stations, the interaction of this variable with station proximity proved redundant and insignificant.

These variables do not cover all the details of TOD. Researchers have used many innovative ways to measure the built environment (Chatman, 2008; Chin *et al.*, 2008; Song and Knapp, 2004; Krizek, 2003; Hess *et al.*, 2001; Frank and Pivo, 1994). However, only a small subset of these variables can realistically fit into a model specification, especially when dealing with a limited number of observations and an even more limited set of neighbourhoods. Due to a lack of data, the analysis particularly misses some of the finer details one might attribute to a good pedestrian environment (for example, levels of street crime, sidewalks, crosswalks, street trees, storefronts and other normative measures of pedestrian quality). Nonetheless, using a few broadly representative variables has the advantage of a more parsimonious specification.

There exists some potential for simultaneity bias when dealing with built environment variables because housing prices can serve as predictors for the type of development that will occur in a neighbourhood (Song and Knapp, 2003). The employment density and park-and-ride variables seem particularly vulnerable to such bias. A two-stage random effects model was estimated in which exogenous instruments substitute for these suspect variables and their associated interaction terms.[23] However, a Hausman test showed that the two-stage model coefficients did not systematically differ from a single equation estimation. The two -stage model was then abandoned, as the single equation model has superior efficiency (i.e. smaller standard errors) (Kennedy, 2003).

Interaction Terms

The statistical interaction between rail proximity and pedestrian quality represents the key element of this research. Thus, before presenting the model results, it seems appropriate to provide a general discussion of interaction terms that clarifies what they are and how they should be interpreted.

Creating an interaction term for a regression model simply requires multiplying two independent variables together and including the resulting product as an additional independent variable. The following is a simple example of a regression equation that includes an interaction term:

$$Y = (b_1 * \mathrm{X}) + (b_2 * \mathrm{Z}) + (b_3 * \mathrm{X} * \mathrm{Z}) \qquad (2)$$

This equation contains an interaction term (b_3*X*Z) and two corresponding constitutive terms (b_1*X) and (b_2*Z). Constitutive terms are defined as those terms containing individual elements of an interaction term. All constitutive terms should remain in an interaction model, even if they have a statistically insignificant coefficient. The exclusion of a constitutive term will bias the coefficients and standard errors of an interaction model (see Brambor *et al.*, 2006, for a detailed statistical assessment of this issue).

The interaction between **X** and **Z** in equation (2) means that the impact of **X** on the dependent variable (**Y**) becomes conditional upon **Z** (and vice versa). Applying some simple algebra to equation (2) yields the marginal coefficient for **X** (Aiken and West, 1991)

$$b_1 + (b_3 * \mathbf{Z}) \tag{3}$$

The standard error that corresponds to a marginal coefficient obtained from equation (3) comes from this formula

$$\sqrt{[\text{variance}(b_1) + \mathbf{Z}^2 * \text{variance}(b_3) + 2\mathbf{Z} * \text{variance}(b_1 b_3)]} \tag{4}$$

In sum, equations (3) and (4) allow a determination of whether **X** has a statistically significant impact on the dependent variable when assuming a given value of **Z**.

Equation (3) illustrates that a constitutive coefficient such as b_1 represents the marginal effect for **X** conditional upon **Z** equalling zero. Because zero frequently falls outside a variable's realistic range, b_1 may not provide useful information as a stand-alone value. However, interactions can be mean-centred to give the constitutive coefficients some substantive meaning (Brambor *et al.*, 2006).[24] This allows b_1 to become the marginal coefficient of **X** conditional upon **Z** equalling its average value (rather than zero). All interaction variables in this analysis are mean-centred and, thus, constitutive terms should be interpreted accordingly. The reader should note that mean-centring provides only a cosmetic improvement. It does not, as commonly believed, reduce multicollinearity or statistically alter the model in any way (Echambadi and Hess, 2007).

Research Findings

Model Results

Table 4 presents the model coefficients, standard errors and significance statistics. The model has a good overall fit with an R^2 above 0.8. The variables mostly have intuitive and significant coefficients. The three interaction terms entered the model simultaneously and each has at least a weakly significant coefficient (between 0.05 and 0.10). Because these interactions play a central role in this analysis, they remained in the model despite the fact that they did not all meet the traditional 0.05 significance level. Some of the constitutive terms have insignificant or weakly significant coefficients. As previously described, it is technically necessary to keep these constitutive variables in the model even when they are not significant.

The mean-centring of interactions means that the coefficients for intersection density (*intsctn*), population-serving job density (*ps_jobs*) and slope represent a marginal effect conditional upon the nearest Trolley station being at a mean distance of 0.98 kilometres away. Further, the coefficient for station distance (ln(*station*)) represents a marginal effect conditional upon simultaneous mean values for intersection density (0.4/hectare), people-serving job density (3.4/hectare) and the slope between the parcel and station (1.4 per cent). Hence, the lack of statistical significance for these constitutive variables applies narrowly to the described conditions. As the subsequent sections will illustrate, the impacts of these variables becomes more significant under alternative conditions.

The Marginal Effect of Station Proximity

The insignificant coefficient for the constitutive ln(*station*) variable indicates no

Table 4. Model results (N = 3374; dependent variable: *price_00*)

	Coefficient	*z*	*P>|z|*
*Unit characteristics (vector **U**)*			
ln(sq_m)	94 129.61	8.07	0.00
age	−3 276.19	−5.81	0.00
age2	41.72	4.86	0.00
bath	4 291.60	2.14	0.03
bed	4 182.21	1.65	0.10
garage	9 136.71	4.80	0.00
view	7 391.63	4.51	0.00
*Neighbourhood characterisics (vector **N**)*			
intrsctn	−3 926.90	−0.42	0.67
ps_jobs	1 431.81	1.63	0.10
slope	5 599.88	3.38	0.00
parking	−9 345.20	−2.93	0.00
hwy50m	−7 669.65	−2.17	0.03
*Transport facilities (vector **T**)*			
ln(*station*)	−3 182.41	−1.18	0.24
Station distance interactions, mean centred			
*intrsctn** ln(*station*)	−14 668.62	−1.69	0.09
*ps_jobs** ln(*station*)	−2 826.29	−3.44	0.00
*slope** ln(*station*)	4 828.52	1.85	0.06
Constant	−340 399.60	−6.73	0.00

Notes: Random effects generalised least squares regression; robust, clustered standard errors; groups/clusters = 439; R^2= 0.8395.

statistically perceptible station area premium when assuming an 'average' pedestrian environment.[25] However, the interaction terms indicate that station distance can become a significant predictor of condo prices conditional upon the pedestrian environment. More specifically, increases in intersection density, increases in people-serving commercial activity or decreases in the steepness of the terrain will enhance the relative value and statistical significance of station proximity.

Of the three variables that have been interacted with station distance, people-serving jobs (*ps_jobs*) clearly has the most significant interaction term. Figure 2 shows the size and statistical significance of the marginal coefficient for station distance as moderated by *ps_jobs*. Where the upper bound of the 95 per cent confidence interval falls below zero, the marginal coefficient is significantly negative (according the traditional 0.05 standard) and when the lower bound falls above zero, the coefficient is significantly positive. In order to isolate the moderating effect of *ps_jobs*, the estimated coefficients in this graph assume that the other two variables with station distance interactions (i.e. *intsctn* and *slope*) are held constant at their mean values. When evaluating this graph, the reader should note that the logarithmic transformation of the station distance variable means that the estimated coefficient roughly translates to the change in price associated with a 1 per cent increase (rather than a 1 kilometre increase) in station distance.

A negative coefficient for station distance indicates a negative price gradient moving away from a station and, consequently, a strongly negative coefficient means that, all other things equal, station-proximate condos will have higher prices. Hence, the increasingly negative coefficient in Figure 2 demonstrates that station proximity becomes more valuable as the level of commercial activity increases. When a condo has no people-serving jobs in the surrounding neighbourhood, the estimated coefficient is actually positive and nearly significant. As the number of these jobs increases, the positive coefficient becomes less significant until, at around two jobs per hectare (the 44th percentile value for *ps_jobs*), the coefficient becomes negative. Above four jobs per hectare (69th percentile), the coefficient becomes negatively significant.

Figure 3 similarly presents variation in the marginal coefficient for station distance, except now the number of intersections per hectare is allowed to vary while people-serving jobs are held constant at their mean. Although the moderating effect of intersection density appears much weaker, Figure 3 illustrates the

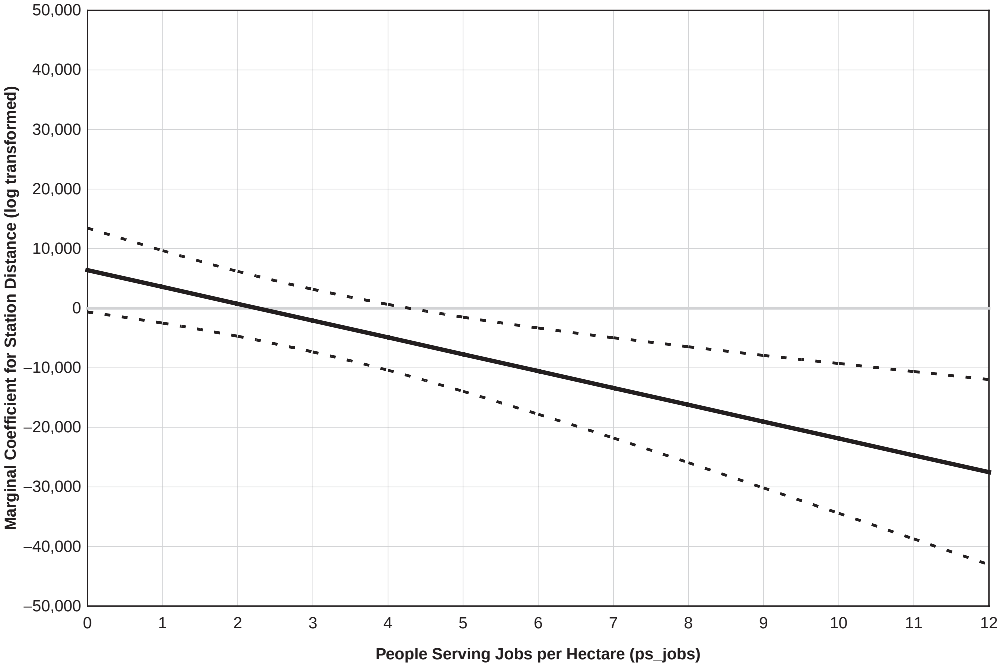

Figure 2. Marginal coefficient for station distance as conditioned by people-serving job density (the dashed lines mark the 95 per cent confidence interval for the coefficient).

same general pattern as Figure 2. Until the number of intersections reaches about 0.2 per hectare (the 38th per centile value for *intsctn*) the coefficient is insignificantly positive. Beyond this point, the coefficient becomes increasingly negative. It becomes significantly negative for intersection densities above 0.6 per hectare (78th percentile).

Figure 4 again graphs the marginal coefficient of station distance but now as moderated by the *slope* variable while holding *ps_jobs* and *intsctn* at their means. This graph has a different pattern from the previous two because the marginal coefficient increases rather than decreases when moving outward along the *x* axis. When the slope between a condo and the nearest station remains below 1 per cent (the 49th percentile for *slope*), the coefficient is negative and significant. For slopes between 1 and 2 per cent (70th percentile), the coefficient becomes insignificant but remains negative. Above a 2 per cent slope, the coefficient becomes positive. As slopes become steeper, the coefficient becomes quite large but the confidence interval becomes equally large so that a positively significant coefficient never occurs.

While these graphs provide good indicators about how these individual components of TOD interact with station distance, holding the other variables at their mean values creates scenarios that may rarely or never occur in reality. The size and significance of the marginal coefficient will obviously depend on the unique combination of values for the three variables interacted with station distance. A neighbourhood that scores well in all dimensions (i.e. a large amount of commercial activity, a well-connected street network and a flat path to the station), is likely to result in a marginal station distance coefficient that surpasses the magnitude and significance level of anything displayed in Figures 2 , 3 or 4.

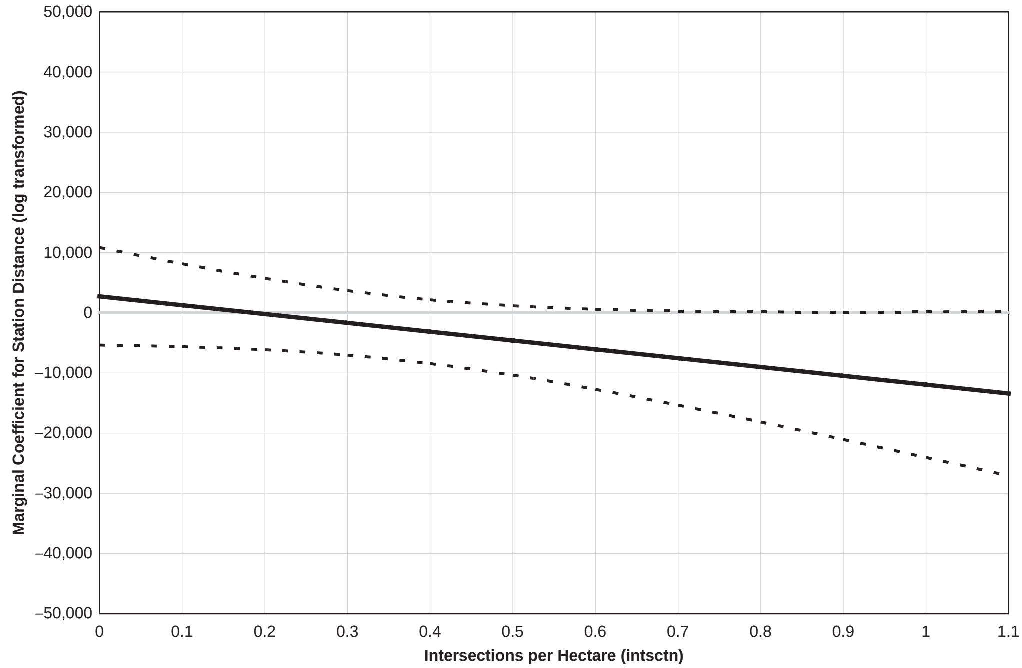

Figure 3. Marginal coefficient for station distance as conditioned by intersection density (the dashed lines mark the 95 per cent confidence interval for the coefficient).

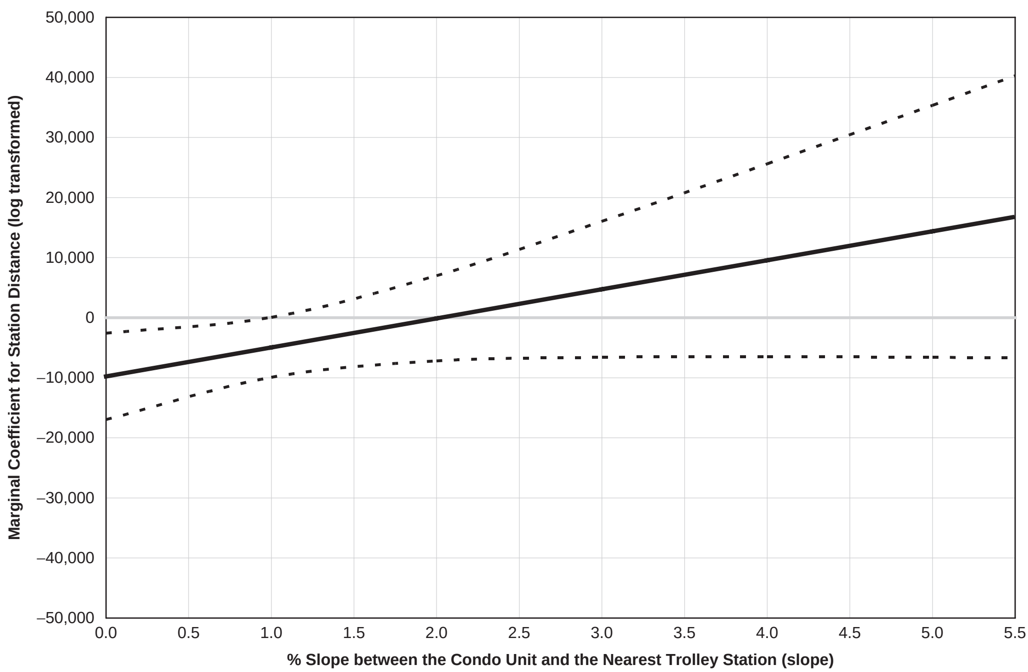

Figure 4. Marginal coefficient for station distance as conditioned by the percentage slope between the condo unit and the nearest station (the dashed lines mark the 95 per cent confidence interval for the coefficient).

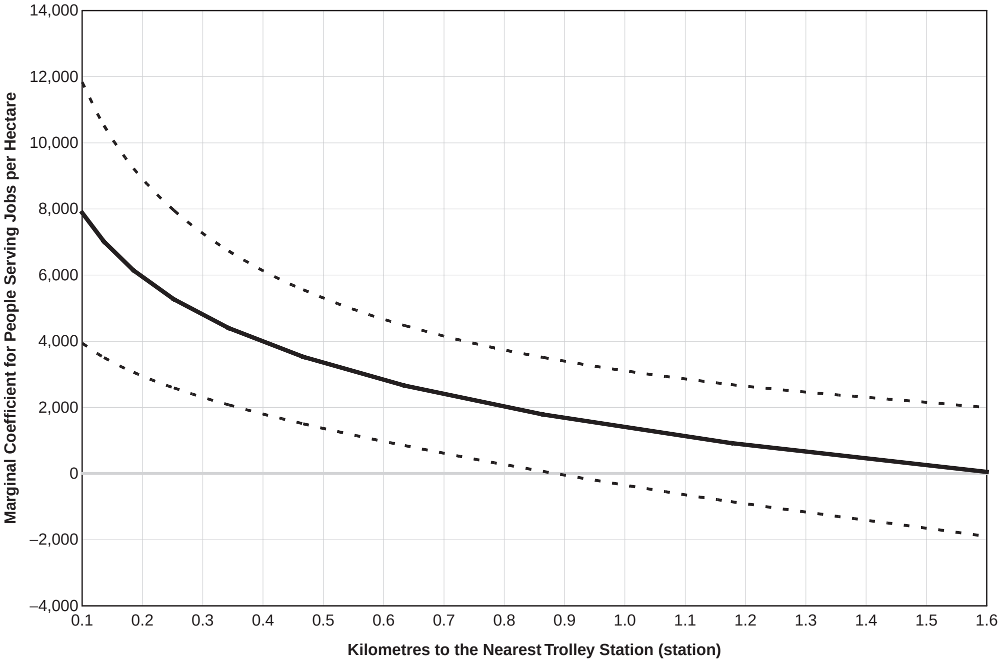

Figure 5. Marginal coefficient for people-serving jobs per hectare as conditioned by station distance (the dashed lines mark the 95 per cent confidence interval for the coefficient).

Coefficient of the Marginal Pedestrian Characteristics

If the pedestrian environment conditions the impact of station proximity on condo prices, station proximity will, by definition, condition the impact of the pedestrian environment. Figure 5 graphs the marginal coefficient for *ps_jobs* with respect to station distance. At 0.1 kilometre, this measure of commercial activity has a strong and positive coefficient. This coefficient then decreases moving outward until becoming insignificant around 0.9 kilometre. When station distance reaches 1.6 kilometres, the coefficient has nearly reached zero. It appears that those on the market for station-proximate housing assign a higher value to commercial activity.

Figure 6 shows the marginal coefficient for intersection density. The coefficient for *intsctn* never reaches full statistical significance. At close proximity to a station, the coefficient approaches positive significance. To a lesser degree, the coefficient approaches negative significance moving away from a station. The coefficient moves from positive to negative at roughly 0.8 kilometre. Again, it appears that those purchasing a station-proximate condo place a higher value, albeit not quite a statistically significant value, on street connectivity.

Figure 7 demonstrates that the *slope* variable has a positive influence on condo prices except at very close proximity to a station. At 0.1 kilometre, the coefficient is negative but insignificant and by 0.3 kilometre the coefficient has quickly become positive. For station distances greater than 0.65 kilometre, slope has a significantly positive effect. Living on a hillside or on top of a hill seems to have some amenity value,[26] but only for condos far enough away from a station that topographic barriers to walking may not matter. However, for those on the market for station-proximate condos, steep terrain acts as barrier to walking to the station and the hillside amenity does not seem to apply.

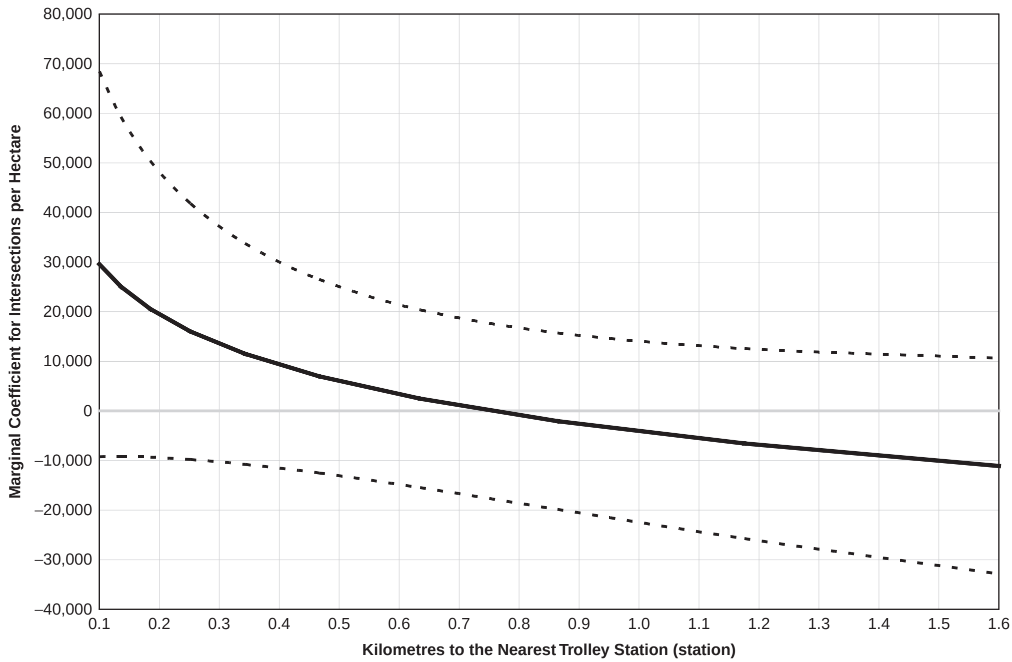

Figure 6. Marginal coefficient for intersection per hectare as conditioned by station distance (the dashed lines mark the 95 per cent confidence interval for the coefficient).

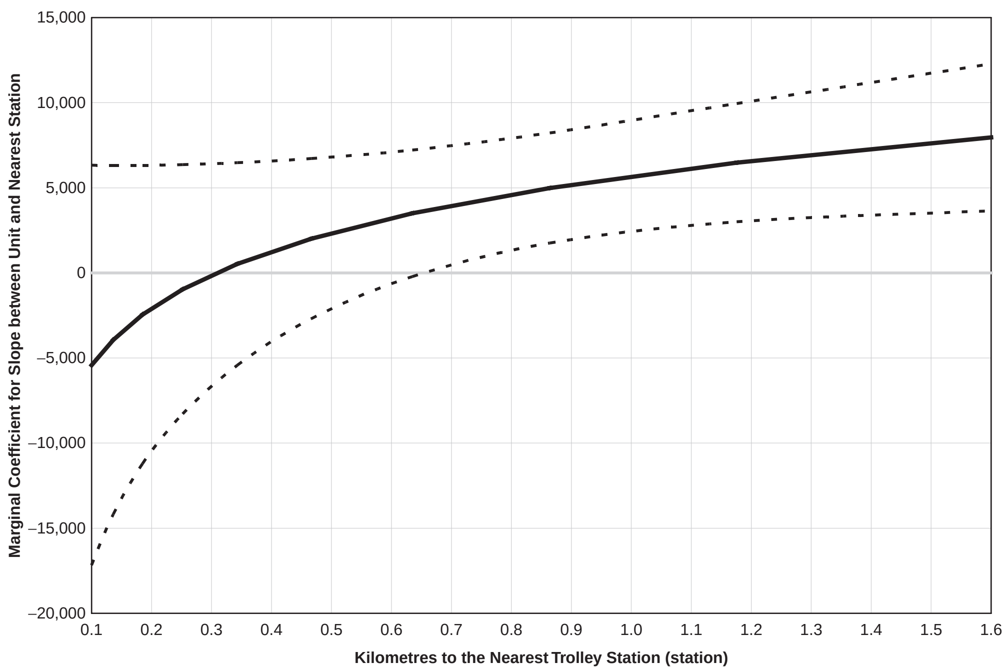

Figure 7. Marginal coefficient for percentage slope between the condo unit and the nearest station as conditioned by station distance (the dashed lines mark the 95 per cent confidence interval for the coefficient).

Comparing Price Gradients

Figure 8 displays two rail distance price gradients based on model estimates for two hypothetical neighbourhood scenarios. The first scenario is a neighbourhood with a good pedestrian orientation, defined as having 75th percentile values for both intersection density (0.54/hectare) and population-serving job density (5.0/hectare). Assuming 75th percentile values ensures that these key pedestrian measures have above average but not unrealistically extreme values. The second scenario offers a less walkable neighbourhood without much commercial activity and with circuitous street patterns. This scenario assumes 25th percentile values for intersection density (0.16/hectare) and population-serving jobs density (0.80/hectare). The *slope* variable is held constant across both scenarios at a relatively flat 1 per cent grade (this happens to approximate the median value for *slope*). This is done because, at least in San Diego, urban neighbourhoods do not necessarily have flatter terrain that their suburban counterparts.[27]

The figure provides a clear visual illustration of a synergistic relationship between a pedestrian-friendly environment and station proximity. For units in a good pedestrian environment, prices sharply decrease with station distance. Those on the market for a pedestrian-friendly neighbourhood seem to put great value on station proximity. Conversely, for condos in a weak pedestrian environment, prices slightly increase with station distance. This suggests that those on the market for a more typical residential neighbourhood place less value on rail access and probably have greater sensitivity to disamenities (real or perceived) of station proximity such as the importation of traffic, noise, strangers and crime to a neighbourhood (Loukaitou-Sideris *et al.* 2002; Al-Mosaind *et al.* 1993).

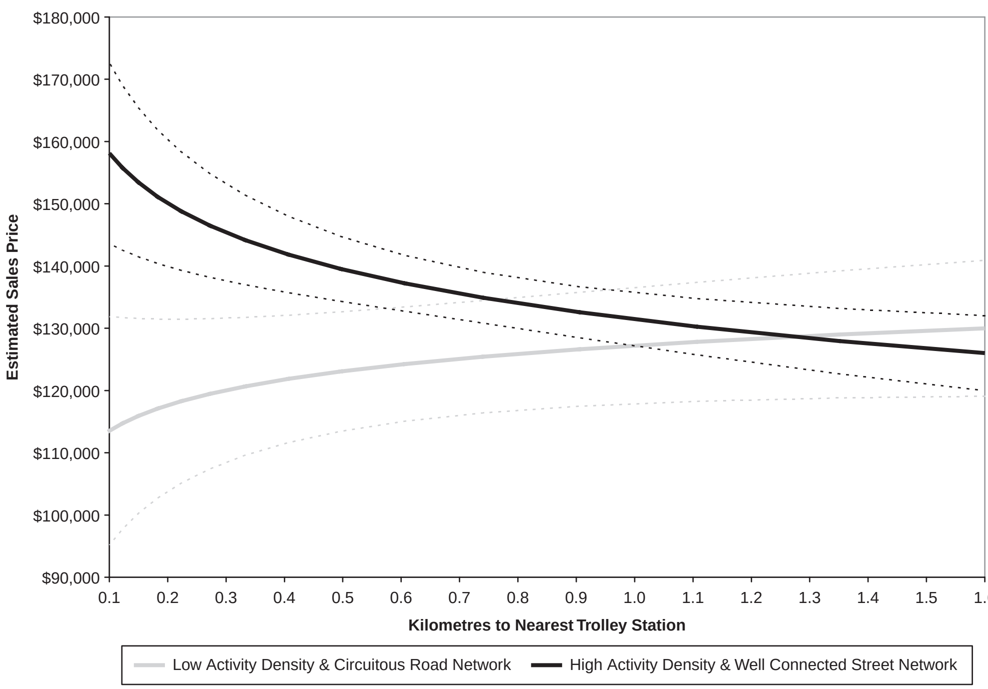

Figure 8. Station distance price gradient by neighbourhood type (the dashed lines mark the 95 per cent confidence intervals for the estimated prices).

At 0.1 kilometre from a station, the good pedestrian neighbourhood has a clear price advantage, as the 95 per cent confidence intervals for the two gradients have no overlap. At about 0.6 kilometre, the confidence intervals begin to overlap and, thus, there exists less statistical distinction between prices in the two neighbourhoods. Finally, at roughly 1.3 kilometres, the two price curves cross. At distance greater than 1.3 kilometres, the weak pedestrian neighbourhood actually has a small, albeit statistically irrelevant, price advantage. If the attraction of TOD has little to do with the rail investment *per se*, as some have suggested (Giuliano, 2004; Bae, 2002), one would expect a good pedestrian neighbourhood to have a price advantage both near and far from the station. Figure 7 presents evidence to the contrary.

Table 5. Estimated station area price premiums/discounts by neighbourhood type (in $)

	Neighbourhood pedestrian quality		
	Good	*Average*	*Poor*
0.3 km from walk-up station	146 257	136 569	120 932
0.3 km from park-and-ride station	141 584	131 896	116 260
1.6 km from station (base price)	126 853	128 306	130 894
Premium/discount			
Walk-up	19 404	8 263	–9 962
	(15.3)	(6.4)	(–7.6)
Park-and-ride	14 731	3 590	–14 643
	(11.6)	(2.8)	(–11.2)

Note: percentages are shown in parentheses.

Estimated Premiums

The transit capitalisation literature (as previously described) often couches empirical results in terms of station area premiums. The conditional nature of the rail distance coefficient, as estimated in this analysis, means that the station area premium will vary considerably depending on neighbourhood characteristics. To keep things simple, this discussion will focus on the hypothetical neighbourhood types defined in the previous section (based on 75th and 25th percentile values for *intsctn* and *ps_jobs*). The table will also include an 'average' neighbourhood that assumes mean values for *intsctn* and *ps_jobs*. As before, a 1 per cent value for *slope* is assumed for all scenarios along with mean values for all other model variables. Table 5 provides the estimated condo price for each neighbourhood type when they are 0.3 kilometre from a walk-up station, 0.3 kilometre from a park-and-ride station,[28] and 1.6 kilometres from a station. The estimated price at 0.3 kilometre distance represents the 'station area' price. The estimated price at 1.6 kilometres acts as a base price (i.e. the price of a property unaffected by a station). The station area premium (or discount) is simply estimated by subtracting the base price from the station area price. The table also presents the premium percentage in relation to the base price.

The estimated station area premium for a good pedestrian neighbourhood approaches $20 000 and can exceed 15 per cent. Conversely, for a neighbourhood with poor pedestrian quality, the model estimates that station area discounts can approach $15 000 and exceed 11 per cent. Park-and-ride lots weaken the premium or strengthen the discount but do not necessarily overwhelm the effect of other neighbourhood characteristics. One would have trouble finding a station area premium or discount of these magnitudes in published studies. However, assuming an 'average' pedestrian environment, the estimated premium falls within the moderate range (<10 per cent) typically demonstrated in the literature (as previously cited). As most previous studies average the station premium over all neighbourhood types, these results actually fit fairly well with the existing body of research.

Conclusion

Summary of Findings

To the degree that the presented price model has a good specification and accurately reflects reality, it provides evidence supporting the previously defined research hypothesis of a synergistic relationship between rail proximity and the pedestrian environment. A condo in a good pedestrian environment and near a station (i.e. TOD) has a significantly higher value than a condo in a similar neighbourhood not near a station. Conversely, a condo in a less walkable residential neighbourhood near a park-and-ride station (i.e. TAD) can have values that actually fall below a condo in a similar neighbourhood not near a station. Hence, TOD does seem to have a synergistic value greater than the sum of its parts, at least in the San Diego condo market.

Caveats

The interpretation of these results requires a few caveats. First, this analysis relies on a cross-sectional model and cannot speak to whether good pedestrian neighbourhoods near Trolley stations had high property values before the introduction of Trolley service. While this does not invalidate the result, it does limit causal inferences. Verifying that prices changes have occurred in concert with the rail system would require a longitudinal model structure that treats the introduction of a rail service as a natural experiment (Meyer, 1995). A few recent transit capitalisation studies have successfully implemented such an approach (Kahn, 2007; Gibbons and Machin, 2005; McMillen and McDonald, 2004). As relevant longitudinal databases become available, more work of this type should follow.

The external validity of this analysis represents another important caveat. San Diego represents a fast-growing and auto-oriented region, which does provide some measure of external validity in a US context. Several neighbouring regions have an existing or planned light rail system and rough similarities in terms size and spatial/temporal growth patterns (for example, Phoenix, Sacramento, Portland, Seattle, Denver and Salt Lake City). These cities might cautiously take lessons from this research. However, relative to other US light rail systems, the Trolley is older and more established, has a strong record of transit-oriented planning and has high patronage (Boarnet and Compin, 1999). San Diego also has the advantage of lacking weather extremes that would deter pedestrian activity (Kuby *et al.*, 2004). Thus, the TOD premiums illustrated for San Diego are likely to serve as an upper bound for other US rail systems in auto-oriented regions.

Even when only considering the San Diego region, one might question the temporal validity of the study findings. The data used for model estimation are now a decade old. Some TOD expansion has certainly occurred in the intervening period and demand has probably increased as well. As the balance between supply and demand changes, so will the price premiums. Future work that examines long-term changes in TOD supply and demand is needed. In particular, an examination of the relationship between TOD price premiums and supply response would provide a valuable extension of this research.

TOD Outlook

The TOD premiums estimated in this analysis signal a healthy demand. Such premiums provide developers with an incentive to produce more TOD housing.[29] This obviously represents an important and necessary condition for TOD to reach the quantity at which it can have an aggregate impact on auto dependence. The rail price gradient illustrated in this analysis also shows that the station area price premium can, under the right circumstance, extend beyond the traditional walking distance of 0.4 kilometre (0.25 mile). If the effective zone for TOD extends beyond this distance, an exponentially greater amount of land area exists that could potentially be converted to TOD.

Assuming a strong market for TOD, the responsibility for an expanded TOD inventory lies with the ability of the public sector to remove and avoid supply constraints (Levine, 2005; Boarnet and Crane, 1998). Given the purported public benefits, one might guess that public agencies would welcome their role in promoting TOD but, in fact, they often have contradictory incentives. For example, some local governments have fiscal and exclusionary incentives to avoid the permissive zoning regulations necessary for TOD to occur (Giuliano, 2004; Cervero and Landis, 1997). Further, a transit agency focused on maximising patronage may favour using the land adjacent to stations for parking rather than TOD (Willson and Menotti, 2007). Value capture schemes and joint development projects in which some share of the TOD premium accrues to public agencies may represent an important way to counter these opposing incentives (Smith and Gihring, 2006; Dumbaugh, 2004).

Despite the contrary incentives, many cities, transit operators and regional agencies in the US have made a strong commitment to TOD (TCRP, 2004). San Diego in particular has made a relatively strong effort to provide the zoning and pedestrian improvements that support TOD (Wilbur Smith Associates, 2006). If these efforts can effectively remove supply constraints, the primary barrier to TOD expansion will lie with the level of market demand. Hence, this research provides some cautious optimism for the growth of TOD in San Diego and, to a lesser extent, other US regions.

Notes

1. The data used for this analysis are now several years old and some TOD expansion has already come to fruition.
2. Those who are economically dependent on transit are not likely to contribute to bidding up the price of TOD.
3. All specific information about the Trolley came from direct communication with and documents obtained from MTS (Metropolitan Transit System), the agency which operates the Trolley.
4. Only the much larger regions of Los Angeles, Boston and San Francisco have light rail systems with more ridership than the Trolley (APTA, 2008).
5. TOD housing should also rightfully include multifamily rental units but obtaining condo sales price data proved much easier than obtaining a full and accurate database of apartment rents. Single-family properties are not necessarily contrary to TOD but, in practice, they usually fall in single-use residential neighbourhoods.
6. More specifically, ‘random effects generalised least squares regression’ was implemented in STATA using the ‘xtreg’ command. A key assumption for such random effects models is that the random intercepts must be uncorrelated with the independent variables (Wooldridge, 2002). A Hausman test indicated that this assumption was not violated and a random effects model was appropriate.
7. Because the parcel groupings share a geographical location, the multilevel format can help to resolve the spatial dependence that is frequently encountered with real estate price models (Pace *et al.*, 1998). However, because the random effects only account for intraparcel dependence, interparcel spatial dependence could still bias model parameters. This interparcel spatial dependence would manifest itself through spatial autocorrelation of the random parcel intercepts. Moran’s I tests (using a range of spatial lags) were applied to the estimated values of these intercepts and revealed no statistically significant clustering.
8. These alternative standard error estimates have the additional property of being robust to the biasing effect of heteroscedasticity (Froot, 1989), which a residual analysis revealed to be present in this analysis.
9. The Trolley is nearly 30 years old and the necessary price and land use data to conduct a longitudinal analysis going this far back were either unavailable or beyond the time and budget available for this research.

10. The database is called Metroscan and is produced by First American Real Estate Solutions.
11. This includes properties where the actual sales price was within 5 per cent of the assessed value of the property (as assessed at the time of the sale). This criterion was established in consultation with the San Diego County Assessor's Office.
12. In an effort to evaluate any temporal variation in TOD premiums across the study period, the data were initially segmented into five groups by year. The relevant coefficients proved relatively stable. Thus, all five years of data were pooled together in one model to take advantage of the statistical benefits of a larger sample size.
13. A model that used a series of 60 dummy variables based on the month/year of sale was also tested in lieu of using a price adjustment. This did not provide measurably different results.
14. If walking to the centre of the CBD (Horton Plaza) takes less time than the out-of-vehicle time (i.e. walk + wait time) associated with a Trolley trip to the same location, the condo was excluded from the analysis.
15. As an assessment of whether this volatility was an isolated issue, other geographical segments of the study area were systematically dropped from the analysis. The large discrepancies caused by CBD properties were found to be unique.
16. In cases where the 400-metre buffer overlapped with the census or land use polygons, data were aggregated to the property in proportion with the share of zone area that fell inside the buffer.
17. Station catchments are used as zones in this analysis to maintain the maximum amount of intrazonal variation in station distance. This is necessary to keep standard errors small for the station distance coefficient, especially given the statistical burden of interaction terms.
18. Being near the tracks, after controlling to proximity to a station, would be expected to have a negative impact on prices. This variable may not be significant in this analysis because light rail is relatively quiet and because condos are frequently located in relatively busy and noisy locations where the additional noise of being near a rail line may not matter much.
19. The income variable was actually significant when treated as an exogenous covariate but when treated endogenously (as it theoretically should be) its coefficient moved much closer to zero and became insignificant. The inclusion or exclusion of this variable did not a have a measurable impact on the coefficients for rail proximity and the associated interaction terms.
20. With a log-linear model, a luxury condo that is worth four times the value of a more typical unit (for example, \$600 000 compared with \$150 000) would be expected to have a TOD price premium four times as large (\$60 000 compared with \$15 000). While there is little theoretical direction on this issue, it seems more intuitive to assume a premium of a fixed amount independent of the underlying property values.
21. Models were tested that simultaneously included variables representing different job categories as well as the mixture of these various categories (for example, an entropy measure). However, these various measures are highly correlated with each other. Thus, including multiple measures resulted in a loss of statistical significance. This justifies the more parsimonious approach of aggregating the most relevant occupations into one category.
22. The slope between a parcel and the nearest station is highly correlated with the average slope within 400 metres of the parcel ($R = 0.68$).
23. More specifically, 'generalised two-stage least squares random effects' estimation was applied in STATA using the 'xtivreg' command. The average slope within 400 metres of the parcel and travel time to the nearest open space preserve (and interactions between these variables and rail proximity) served as the excluded exogenous variables in this estimation. An 'overid' test showed that these variables were sufficiently uncorrelated with condo prices.
24. Mean-centring is accomplished by subtracting the mean value from the individual variables before multiplying them together.
25. A model without interaction terms was also tested and the rail distance coefficient was still insignificant. This indicates that the insignificance of station proximity in an 'average' neighbourhood is not just a by-product of collinearity with the interaction terms.

26. The hillside premium is likely to result from the seclusion and exclusivity of living above the commercial/industrial corridors that the Trolley right-of-way generally follows.
27. Some of the steepest terrain in the study area occurs just a few miles north of the CBD. As illustrated in Table 3, the *slope* variable actually has a positive correlation with *intsctn*. The correlation of *slope* with *ps_jobs* is -0.44, which is not excessively strong.
28. To estimate the impact of a park-and-ride station, the *parking* variable is set at 0.5 hectare. Assuming 360 parking spaces per hectare (Willson and Menotti, 2007), this equates to a surface park-and-ride lot with just under 200 spaces.
29. This assumes that TOD does not have disproportionately high construction costs that would offset any premium value (Gyourko and Saiz, 2006).

Acknowledgements

This research was partially supported by a dissertation grant from the Lincoln Institute of Land Policy. The author would like to thank Robert Cervero and John Quigley for their advice and encouragement in conducting this research. The author would also like to thank the anonymous referees whose suggestions have greatly improved this paper.

References

Aiken, L. and West, S. (1991) *Multiple Regression: Testing and Interpreting Interactions*. London: Sage Publications.

Allen, W., Chang, K., Marchetti, D. and Pokalski, J. (1986) *Value capture in transit: the case of the Lindenwold high speed line*. The Wharton Transportation Program, The Wharton School, University of Pennsylvania.

Al-Mosaind, M., Dueker, K. and Strathman, J. (1993) Light-rail transit stations and property values: a hedonic price approach, *Transportation Research Record*, 1440, pp. 90–94.

Alonso, W. (1964) *Location and Land Use*. Cambridge, MA: Harvard University Press.

APTA (American Public Transportation Association) (2008) *Light rail transit ridership report*. APTA, Washington, DC.

Arrington, G. and Cervero, R. (2008) *Effects of TOD on housing, parking, and travel*. Report 128, Transit Cooperative Research Program,Washington, DC.

Bae, C. (2002) Orenco Station, Portland, Oregon: a successful transit oriented development experiment?, *Transportation Quarterly*, 56, pp. 9–18.

Bajic, V. (1983) The effects of a new subway line on housing prices in metropolitan Toronto, *Urban Studies*, 2, pp. 147–158.

Bernick, M. and Cervero, R. (1997) *Transit Villages in the 21st Century*. New York: McGraw Hill.

Black, A. (1995) *Urban Mass Transportation Planning*. New York: McGraw-Hill.

Boarnet, M. and Compin, N. (1999) Transit-oriented development in San Diego County: the incremental implementation of a planning idea, *Journal of the American Planning Association*, 65, pp. 80–95.

Boarnet, M. and Crane, R. (1998) Public finance and transit-oriented planning: new evidence from southern California, *Journal of Planning Education and Research*, 17, pp. 206–219.

Boarnet, M. and Crane, R. (2001) *Travel by Design: The Influence of Urban Form on Travel*. Oxford: Oxford University Press.

Boarnet, M., Greenwald, M. and McMillan, T. (2008) Walking, urban design, and health: toward a cost–benefit analysis framework, *Journal of Planning Education and Research*, 27, pp. 341–358.

Bourassa, S., Hoesli, M. and Peng, V. (2003) Do housing submarkets really matter?, *Journal of Housing Economics*, 12, pp. 12–28.

Bowes, D. and Ihlanfeldt, K. (2001) Identifying the impacts of rail transit stations on residential property values, *Journal of Urban Economics*, 50, pp. 1–25.

Bragado, N. (1999) Transit joint development in San Diego: policies and practices, *Transportation Research Record*, 1669, pp. 22–29.

Brambor, T., Clark, W. and Golder, M. (2006) Understanding interaction models: improving empirical analyses, *Political Analysis*, 14, pp. 63–82.

Cassel, E. and Mendelsohn, R. (1985) The choice of functional forms for hedonic price equations: comment, *Journal of Urban Economics*, 18, pp. 135–142.

Cervero, R. (1997) *Transit-induced accessibility and agglomeration benefits: a land market evaluation*.

Working Paper No. 691, Institute of Urban and Regional Development, Berkeley, CA.

Cervero, R. (2007) Transit-oriented development's ridership bonus: a product of self-selection and public policies, *Environment and Planning A*, 39, pp. 2068–2085.

Cervero, R. and Duncan, M. (2002a) Benefits of proximity to rail on housing markets: experiences in Santa Clara County, *Journal of Public Transportation*, 5, pp. 1–18.

Cervero, R. and Duncan, M. (2002b) Transit's value-added: effects of light and commuter rail services on commercial land values, *Transportation Research Record*, 1805, pp. 8–15.

Cervero, R. and Duncan, M. (2003) Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay area, *American Journal of Public Health*, 93, pp. 1478–1483.

Cervero, R. and Landis, J. (1997) Twenty years of the Bay Area rapid transit system: land use and development impacts, *Transportation Research A*, 34, pp. 309–333.

Cervero, R., Ferrell, C. and Murphy, S. (2002) *Transit-oriented development and joint development in the United States: a literature review*. Research Results 52, Transit Cooperative Research Program, Washington, DC.

Chatman, D. (2008) Deconstructing development density: quality, quantity and price effects on household non-work travel, *Transportation Research A*, 42, pp. 1008–1030.

Chin, G., Niel, K. van, Giles-Corti, B. and Knuiman, M. (2008) Accessbility and connectivity in physical activity studies: the impacts of missing pedestrian data, *Preventive Medicine*, 46, pp. 41–45.

Crane, R. (2000) The influence of urban form on travel: an interpretive review, *Journal of Planning Literature*, 15, pp. 3–23.

Damm, D., Lerman, S. Lerner-Lam, E. and Young, J. (1980) Response of urban real estate values in anticipation of the Washington Metro, *Journal of Transport Economics and Policy*, 14, pp. 46–61.

Debrezion, G., Pels, E. and Rietveld, P. (2007) The impact of railway stations on residential and commercial property value: a meta-analysis, *The Journal of Real Estate Finance and Economics*, 35, pp. 161–180.

Dewees, D. (1976) The effect of a subway on residential property values in Toronto, *Journal of Urban Economics*, 3, pp. 357–369.

Dittmar, H. and Poticha, S. (2003) Defining transit-oriented development: the new regional building block, in: H. Dittmar and G. Ohland (Eds) *The New Transit Town: Best Practices in Transit-oriented Development*, pp. 19–40. Washington, DC: Island Press.

Downs, A. (1994) *New Visions for Metropolitan America*. Washington, DC: Brookings Institution Press.

Dumbaugh, E. (2004) Overcoming financial and institutional barriers to TOD: Lindbergh Station case study, *Journal of Public Transportation*, 7, pp. 43–69.

Echambadi, R. and Hess, J. (2007) Mean-centering does not alleviate collinearity problems in moderated multiple regression models, *Marketing Science*, 26, pp. 438–445.

Eppli, M. and Tu, C. (1999) *Valuing the New Urbanism: The Impact of the New Urbanism on Prices of Single-family Homes*. Washington, DC: Urban Land Institute.

Ewing, R. and Cervero, R. (2001) Travel and the built environment: a synthesis, *Transportation Research Record*, 1780, pp. 87–114.

Ewing, R., Pendall, R. and Chen, D. (2003) Measuring sprawl and its transportation impacts, *Transportation Research Record*, 1831, pp. 175–183.

Frank, L. and Pivo, G. (1994) Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking, *Transportation Research Record*, 1466, pp. 44–52.

Frank, L., Kerr, J., Sallis, J. *et al.* (2008) A hierarchy of sociodemographic and environmental correlates of walking and obesity, *Preventive Medicine*, 47, pp. 172–178.

Friedrich, R. (1982) In defense of multiplicative terms in multiple regression equations, *American Journal of Political Science*, 26, pp. 797–833.

Froot, K. (1989) Consistent covariance matrix estimation with cross-sectional dependence and heteroskedasticity in financial data, *Journal of Financial and Quantitative Analysis*, 24, pp. 333–355.

Gatzlaff, D. and Smith, M. (1993) The impact of the Miami metrorail on the value of residences near station locations, *Land Economics*, 69, pp. 54–66.

Gibbons, S. and Machin, S. (2005) Valuing rail access using transport innovations, *Journal of Urban Economics*, 57, pp. 148–169.

Giuliano, G. (2004) Land use impacts of transportation investments: highway and transit, in: S. Hanson and G. Giuliano (Eds) *The Geography of Urban Transportation*, 3rd edn, pp. 237–273. New York: Guilford Press.

Givoni, M. and Rietveld, P. (2007) The access journey to the railway station and its role in passenger satisfaction with rail travel, *Transport Policy*, 14, pp. 357–365.

Goodman, A. and Thibodeau, T. (1998) Housing market segmentation, *Journal of Housing Economics*, 7, pp. 121–143.

Gyourko, J. and Saiz, A. (2006) Construction costs and the supply of housing structure, *Journal of Regional Science*, 46, pp. 661–680.

Hemily, B. (2004) *Trends affecting public transit's effectiveness*. American Public Transit Association, Washington, DC.

Hess, D. and Almeida, T. (2007) Impact of proximity to light rail rapid transit on station-area property values in Buffalo, New York, *Urban Studies*, 44, pp. 1041–1068.

Hess, P., Moudon, A. and Logsdon, M. (2001) Measuring land use patterns for transportation research, *Transportation Research Record*, 1780, pp. 17–24.

Huang, H. (1996) The land-use impacts of urban rail transit systems, *Journal of Planning Literature*, 11, pp. 17–30.

Kahn, M. (2007) Gentrification trends in new transit-oriented communities: evidence from 14 cities that expanded and built rail transit systems, *Real Estate Economics*, 35, pp. 155–182.

Kennedy, P. (2003) *A Guide to Econometrics*. Cambridge, MA: MIT Press.

Kim, S., Ulfarsson, G. and Hennessy, J. T. (2007) Analysis of light rail rider travel behavior: impacts of individual, built environment, and crime characteristics on transit access, *Transportation Research A*, 41, pp. 511–522.

Krizek, K. (2003) Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling, *Journal of Planning Education and Research*, 22, pp. 270–287.

Krizek, K. (2006) Lifestyles, residential location decisions, and pedestrian and transit activity, *Transportation Research Record*, 1981, pp. 171–178.

Kuby, M., Barranda, A. and Upchurch, C. (2004) Factors influencing light-rail station boardings in the United States, *Transportation Research A*, 38, pp. 223–247.

Landis, J., Guhathakurta, S., Huang, W. *et al.* (1995) *Rail transit investments, real estate values, and land use change: a comparative analysis of five California rail transit systems*. Monograph No. 48, Institute of Urban and Regional Development, Berkeley, CA.

Levine, J. (2005) *Zoned Out: Regulation, Markets, and Choices in Transportation and Metropolitan Land Use*. Washington, DC: RFF Press.

Levine, J. and Frank, L. (2007) Transportation and land-use preferences and residents' neighborhood choices: the sufficiency of compact development in the Atlanta region, *Transportation*, 34, pp. 255–274.

Loukaitou-Sideris, A., Liggett, R. and Iseki, H. (2002) The geography of transit crime: documentation and evaluation of crime incidence on and around the Green Line stations in Los Angeles, *Journal of Planning Education and Research*, 22, pp. 135–151.

Lund, H. (2006) Reasons for living in a transit-oriented development, and associated transit use, *Journal of the American Planning Association*, 72, pp. 357–366.

Malpezzi, S. (2002) Hedonic pricing models and house price indexes: a select review, in: K. Gibb and A. O'Sullivan (Eds) *Housing Economics and Public Policy: Essays in Honour of Duncan Maclennan*, pp. 67–89. Oxford: Blackwell Publishing.

McMillen, D. and McDonald, J. (2004) Reaction of house prices to a new rapid transit line: Chicago's Midway Line, 1983–1999, *Real Estate Economics*, 32, pp. 463–486.

Meyer, B. (1995) Natural and quasi-experiments in economics, *Journal of Business and Economic Statistics*, 13, pp. 151–161.

Mokhtarian, P. and Cao, X. (2008) Examining the impacts of residential self-selection on travel behavior: a focus on methodologies, *Transportation Research B*, 43, pp. 204–228.

Mouden, A., Lee, C., Cheadle, A. *et al.* (2006) Operational definitions of walkable neighborhood: theoretical and empirical insights, *Journal of Physical Activity and Health*, 3, pp. 99–117.

Moulton, B. (1990) An illustration of a pitfall in estimating the effects of aggregate variables on micro units, *Review of Economics and Statistics*, 72, pp. 334–338.

Muth, R. (1969) *Cities and Housing*. Chicago, IL: University of Chicago Press.

Nelson, A. (1992) Effects of elevated heavy-rail transit stations on house prices with respect to neighborhood income, *Transportation Research Record*, 1359, pp. 127–132.

Pace, K., Barry, R. and Sirmans, C. (1998) Spatial statistics and real estate, *The Journal of Real Estate Finance and Economics*, 17, pp. 5–13.

Pucher, J. and Renne, J. (2003) Socioeconomics of urban travel: evidence from the 2001 NHTS, *Transportation Quarterly*, 57, pp. 49–77.

Raudenbush, S. and Bryk, A. (2001) *Hierarchical Linear Models: Applications and Data Analysis Methods*, 2nd edn. Thousand Oaks, CA: Sage Publications.

Rosen, S. (1974) Hedonic prices and implicit markets: product differentiation in pure markets, *Journal of Political Economics*, 82, pp. 34–55.

Ryan, S. (1999) Property values and transportation facilities: finding the transportation–land use connection, *Journal of Planning Literature*, 13, pp. 412–427.

Ryan, S. (2005) The value of access to highways and light rail transit: evidence for industrial and office firms, *Urban Studies*, 42, pp. 751–764.

Saelens, B. and Handy, S. (2008) Built environment correlates of walking: a review, *Medicine & Science in Sports & Exercise*, 40, pp. 550–566.

Schlossberg, M. and Brown, N. (2004) Comparing transit-oriented development sites by walkability indicators, *Transportation Research Record*, 1887, pp. 34–42.

Schwanen, T. and Mokhtarian, P. (2004) The extent and determinants of dissonance between actual and preferred neighborhood type, *Environment and Planning B*, 31, pp. 759–784.

Singleton, R. and Straits, B. (1999) *Approaches to Social Research*, 3rd edn. Oxford: Oxford University Press.

Smith, J. and Gihring, T. (2006) Financing transit systems through value capture: an annotated bibliography, *American Journal of Economics and Sociology*, 65, pp. 751–786.

Song, Y. and Knapp, G. (2003) New urbanism and housing values: a disaggregate assessment, *Journal of Urban Economics*, 54, pp. 218–238.

Song, Y. and Knapp, G. (2004) Measuring urban from: is Portland winning the war on sprawl?, *Journal of the American Planning Association*, 70, pp. 210–225.

Steiner, R. (1995) Residential density and travel patterns: a review of the literature, *Transportation Research Record*, 1466, pp. 37–43.

TCRP (Transit Cooperative Research Program) (1996) *Transit and urban form*. Report No. 16, TCRP, Washington, DC.

TCRP (2004) *Transit-oriented development in the United States: experiences, challenges, and prospects*. Report No. 102, TCRP, Washington, DC.

TCRP (2008) *Understanding how indivduals make travel and location decsicions: implications for public transportation*. Report No. 123, TCRP, Washington, DC.

TRB (Transportation Research Board) and IOM (National Academies' Institute of Medicine) (2005) *Does the built environment influence physical activity? Examining the evidence*. Special Report No. 282, TRB, Washington, DC.

Vessali, K. (1996) Land use impacts of rapid transit: a review of the empirical literature, *Berkeley Planning Journal*, 11, pp. 71–105.

Weinberger, R. (2001) Light rail proximity: benefit or detriment in the case of Santa Clara County, California?, *Transportation Research Record*, 1747, pp. 104–113.

White, M. (1999) Urban areas with decentralized employment: theory and empirical work, in: E. Mills and P. Cheshire (Eds) *Handbook of Regional and Urban Economics, Vol. 3*, pp. 1375–1412. Amsterdam: Elsevier Science.

Wilbur Smith Associates (2006) *Independent transit planning review services*. San Diego Association of Governments, CA.

Willson, R. and Menotti, V. (2007) Commuter parking versus transit-oriented development: evaluation methodology, *Transportation Research Record*, 2021, pp. 188–125.

Wooldridge, J. (2002) *Econometric Analysis of Cross-section and Panel Data*. Cambridge, MA: MIT Press.