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The role of commuter rail accessibility in the formation of residential land values: Exploring spatial heterogeneity in peri-urban and remote areas

Rémy LE BOENNEC ^{1,*}, Julie BULTEAU ², Thierry FEUILLET ³

¹ VEDECOM Institute, 23 bis, Allée des Marronniers, 78000 Versailles, France. <https://orcid.org/0000-0003-0275-1345>

² University of Paris-Saclay, UVSQ, CEARC, 78280, Guyancourt, France. <https://orcid.org/0000-0002-7488-8407>

³ Université Paris 8, LADYSS, UMR 7533 CNRS, 93526 Saint-Denis, France : <https://orcid.org/0000-0002-5494-538X>

*Corresponding author: remy.leboennec@gmail.com

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Abstract: As an alternative to private car, rail accessibility is part of environmental policies. The effects of light or heavy rail have been widely covered by the literature in urban areas. High-speed rail accessibility has been extensively studied at national or regional scales as well. In-between, only few studies have considered commuter rail accessibility at the scale of metropolitan areas. However, more and more households in Europe have been settling in peri-urban or remote areas around large conurbations, driven by the significant increase in residential land values since 2000. In this article we aimed to uncover, through hedonic pricing, the effect of commuter rail accessibility in the formation of residential land values in the Loire-Atlantique *Département* in France (around the conurbation of Nantes *Métropole*). We used at first an Ordinary Least Square model (OLS). Since nonlinear relationship between proximity to public transport and land values is commonly assumed, we previously applied a generalized additive model (GAM) that revealed threshold effects. To explore spatial heterogeneity in the relationship between commuter rail accessibility and residential land values, we used subsequently a Multiscale Geographically Weighted Regression model (MGWR). We found sound evidence of commuter rail accessibility effect in two specific areas: in the peri-urban area of Nantes *Métropole*, North of the conurbation, and in a remote area, in the Western part of the *Département*. The emphasis of commuter rail accessibility should help decision-makers to convert rail stations into multimodal exchange poles to contain the modal share of private car in peri-urban and remote areas.

Keywords: rail accessibility; residential land value; hedonic pricing; spatial heterogeneity; Generalized Additive Model (GAM); Multiscale Geographically Weighted Regression (MGWR)

JEL Codes: C21, R21, R41, R42

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1. Introduction

Urban mobility patterns have long been analyzed in the transportation literature. One common analytical feature is the identification of the factors that underlie those patterns and produce mobility flows, such as mobility attractors (Katranji et al. 2020). The counterpart of this analysis is to consider the way in which mobility users meet these attractors, through mode-choice analysis (Cervero 2002; Schwanen and Mokhtarian 2005; Scheiner 2010; Ye and Titheridge 2017). An additional step lists the negative environmental externalities associated with individual motorized mobility via the massive use of single-occupant cars (Verhoef 1996).

Environmental instruments aimed at correcting those externalities, such as taxation (Bulteau 2016) and tradable-emission quotas (Bulteau 2012), may reduce individual motorized mobility in favor of active modes and collective and shared mobility. These latter are commonly assumed by policy-makers to be more environmentally-friendly. Conurbations will play a crucial role in delivering this strategy. They are already implementing incentives for low-emission alternative energies and vehicles, encouraging walking and cycling, public transport and car-sharing /pooling schemes to reduce congestion and pollution.¹

Despite the efforts made, there is a gap in most European countries since 2000 (including France) between urban areas (conurbations), where housing is increasingly costly, and peri-urban areas (in the sense of the extra-urban part of metropolitan areas), where a majority of households working in the conurbation settle. In France between 2006 and 2011, the annual population growth was four times higher in the peri-urban areas around major conurbations (offering more than 10,000 jobs) than in the conurbations themselves (+1.2% versus +0.3). Although this gap has narrowed since (+0.8% versus +0.4 between 2011 and 2016), there are still twice as many households moving into the peri-urban areas around the major conurbations in France as there are moving into the conurbations themselves (Source: *INSEE*²). However, research on mobility patterns in these areas is far less developed than that

¹ https://ec.europa.eu/clima/policies/transport_en, accessed January 13th, 2022

in conurbations. This is partly due to the larger role played by individual motorized mobility there, where public transport faces serious difficulties in ensuring efficient trips, given the longer distances and fewer users, as human density falls (Le Boennec and Sari 2015).

In France, public transport is mostly found in peri-urban and remote areas in the form of commuter trains (or buses in the absence of a commuter rail station in the central city). A certain number of railway lines are menaced by the perspective of the national operator, the SNCF (*Société Nationale des Chemins de Fer*), being opened to competition in 2023. Providing a comprehensive framework of the influence of commuter rail stations on travel behavior is thus a prerequisite for the future of mobility outside major conurbations. Should massive public funding be allocated to develop or maintain a competitive commuter rail offer compared to private cars around cities and in remote areas, including the design of costly modal-exchange poles near commuter rail stations? Or should public authorities encourage shared mobility in these areas, especially carpooling, at probably lower cost?

In this article, we explore the effect of commuter rail accessibility through an hedonic pricing analysis applied to residential land values in the peri-urban area of the conurbation of Nantes *Métropole* (encompassing the central city of Nantes and 23 suburban municipalities) and the remote areas of the Loire-Atlantique *Département* (L.A.), in the North-West of France. We do not look at land sales within Nantes *Métropole*. The analysis we conduct here is close to Bulteau et al. (2018). However, this article considers land values in the peri-urban and remote areas of the Loire-Atlantique *Département*, whereas Bulteau et al. (2018) focus on house prices in Nantes *Métropole* and its peri-urban areas. Moreover, the authors evaluate the value of alternatives to single-occupant car use (tram, bike-sharing, carsharing, commuter rail station etc.) in applying the hedonic pricing method to residential housing, while we explore here specifically the effect of commuter rail accessibility in applying hedonic pricing to residential land values. Finally, statistical methodologies differ: we here rely on an Ordinary Least Square (OLS) regression, using the derived thresholds of a Generalized Additive Model (GAM) to discretize the distance to the nearest commuter rail station; then we estimate a multiscale geographically weighted regression (MGWR) to test spatial heterogeneity between local contexts. Bulteau et al. (2018) use spatial regression models (Spatial AutoRegressive, Spatial Error, Spatial Durbin models

and Geographically Weighted Regression) to capture the effect of both spatial autocorrelation and spatial heterogeneity.

Indeed, as noted above, the influence of rail accessibility has often been analyzed in urban areas, both in France and elsewhere. On the contrary, to our knowledge, this is the first French study considering the influence of commuter rail stations in peri-urban and remote areas. Moreover, only few hedonic studies consider land instead of property values. Last, the current study is the first to include a MGWR to analyze commuter rail accessibility out of urban areas.

The remainder of the paper is structured as follows. Section 2 sets out the theoretical and empirical framework for the formation of residential land values. We describe the data and methods used in Section 3. Section 4 then presents and discusses the results. Last, Section 5 concludes.

2. Literature review

Urban economics set the theoretical framework of the role of accessibility through the analysis of the interactions between the location choices of economic agents and mobility patterns. Household residential location choices reflect individual trade-offs between land cost and commuting cost under the budget constraint, with land cost being lower and commuting cost higher as accessibility to the nearest conurbation decreases. Theoretical models in urban economics describe this trade-off (Alonso 1964; Fujita 1989; Brueckner 2011). These models can include negative externalities from individual motorized mobility: greenhouse gas emissions (GHG), air pollution, noise exposure and road safety (Kanemoto 1980; Verhoef and Nijkamp 2008; Le Boennec 2014).

The empirical tools here include the stated-preference methods applied to household residential-location choices, where these reveal their preferences over amenities and transport (Lund 2006; Cao et al. 2009; Cao and Cao 2014). The role of the life cycle in residential preferences is emphasized (such as the birth of a child: Clark and Onaka 1983; Rabe and Taylor 2010). More generally, global satisfaction with housing appears in these analyses (Kytta et al. 2016; Nowok et al. 2018; Le Boennec and Lucas 2021).

Another approach identifies residential-location factors through the analysis of revealed preferences of households. The hedonic pricing method (Rosen 1974) remains popular due to its relevance regarding the interactions between housing and mobility patterns. In the hedonic pricing method, the real-estate market indirectly provides a monetary value for the intrinsic attributes of a property or its accessibility. The difference in prices between two properties with and without an attribute provides an estimate of the value of that attribute, for example proximity to transport (Brécard et al. 2018).

Apart from the intrinsic attributes of a property (surface area, number of rooms, presence of parking or a balcony, etc.), the role of neighborhood characteristics on property values continues to be frequently analyzed as a first group of extrinsic attributes (the unemployment rate, criminality level, presence of social housing, etc.). These attributes are commonly included in models of house prices, as mentioned for example by Cavailhès (2005). Accessibility is a second group of extrinsic characteristics: proximity to the Central Business District, major road arteries, public-transport networks and various types of facilities and amenities, such as green spaces (Cho et al. 2006; Kong et al. 2007; Czembrowski and Kronenberg 2016).

The hedonic pricing literature considering rail accessibility in urban areas is plentiful : *light rail* in Buffalo, US (Hess and Almeida 2007), in Dublin, Ireland (Mayor et al. 2012), and in Kuala Lumpur, Indonesia (Dziauddin 2019); *heavy rail* in Bangkok, Thailand (Chalermpong 2007), in Brisbane, Australia (Mulley et al. 2016), and in Laval, Canada (Devaux et al. 2017); and *commuter rail*, that we will present afterwards. Conversely, regional studies considering extra-urban areas focus mostly on high-speed rail for long-distance trips, especially in Eastern Asia (Andersson et al. 2012; Chen and Hayes 2015; Zhou et al. 2018; Yu 2021). Far less studied is commuter rail accessibility in peri-urban or remote areas.

Land values are also far less considered than property values in the hedonic pricing literature. Apart Mohammad et al. (2013), we found no recent study that considered plots instead of residential or commercial properties for commuter rail accessibility. This could be related to several reasons. First, because there are fewer intrinsic attributes than for housing (surface area, slope, utility connections, etc.).

Second, high correlation levels between the areas frequently under consideration (urban areas) and the scarcity of vacant land in built-up areas are noticed. However, a sound understanding of the formation of residential land values is important for several reasons. First, an adjustment in housing *versus* land markets following a given shock may be more or less rapid (Oikarinen 2014). Second, as house prices reflect both construction costs and land values (Ay et al. 2018; Tideman and Plassmann 2018), and the way in which these two costs change over time may be quite dissimilar (Davis and Palumbo 2008; Kuminoff and Pope 2013).

We here consider hedonic studies that analyze commuter rail accessibility at the metropolitan area scale. It appears to be a delicate task, as a definition of a metropolitan area may vary worldwide. We did not retain the studies that strictly considered a city center or a conurbation. In the end, we identify 11 studies since 2000 that apply the hedonic pricing method for the consideration of commuter rail accessibility in such geographical areas (Table 1).

Table 1. List of the hedonic studies considering commuter rail accessibility at metropolitan area scale

Authors	Rail system	Area designation	Area size (km ²)	Area pop.	Nb CR stations	Prop. Type	Obs.	Period	Method	Major results
Bowes and Ihlanfeldt (2001)	Rapid transit	MA Atlanta, US	-	-	31	R	22,388	1991-1994	OLS	*Prop. <0.25 mile from a rail station <19% value than beyond 3 miles. *Prop. between 1-3 miles => significantly higher value compared to those farther away.
Cervero and Duncan (2002a)	LR, CR	Santa Clara County, US	3,377	1,680,000	-	R	7,100	1999	OLS	A premium of 20% in land values for CR
Cervero and Duncan (2002b)	LR, HR, CR	Los Angeles County, US	12,310	9,800,000	49	C, R	58,231	2000	OLS	'Uneven and inconsistent' results
Armstrong and Rodriguez (2006)	CR	4 municipalities in MA Boston, US	-	-	-	R	1,860	1992-1993	OLS	*Prop. <0.5 mile of a CR station exhibit values >10.1% *Prop. in municipalities with CR stations >9.6%-10.1% values.
Cervero (2006)	LR, CR	San Diego County, US	11,722	2,840,000	-	C, R	26,295	2000	OLS	Condominiums and single-family housing enjoyed premiums along all corridors, with the largest benefit accruing to properties near CR stations.
Debrezion, Pels, Rietveld (2007)	LR, HR, CR	57 MA in the US (meta-analysis)	-	-	-	C, R	57	1976-2002	OLS	*Rail station proximity has a higher effect on commercial prop. compared to residential (threshold effect=0.25 mile) *HR and CR effects >LR effects
Debrezion, Pels and Rietveld (2011)	LR, HR, CR	3 MA in the Netherlands (Amsterdam, Rotter-	-	-	-	R	64,095	1996-2001	OLS	*Prices influenced more by the most frequently chosen station than by the nearest rail station.

		dam, Enschede)								*Bigger differences in results for more urbanized areas.
Dubé, Thériault and Des Rosiers (2013)	CR	MA Montréal, Canada	-	-	6	R (repeat sales)	39,099	1992-2009	DID	*A market premium which decreases with distance, from 9.7% of mean sale price within a 0–500 m radius down to 2.7% within the 1000–1500 m buffer.
Mohammad Graham, Melo and Anderson (2013)	LR, HR, CR	80 cities in US, Europe, Asia (meta-analysis)	-	-	-	L, R	102	1980-2007	Random effect model	*Land value changes are higher than property value changes. * Changes for commercial land uses tend to be higher than for residential. *Higher impacts of CR on land/property value changes in comparison to LR. *Land/prop. value changes tend to be higher at 500-805 m distances of a rail station, compared to >0.5 mile. *Higher rail impact in European and East Asian cities compared to cities in North America
Bohman and Nilsson (2016)	CR	Scania Region, Sweden	11,027	1,300,000	60	R	8,489	2014	Quantile regression	*Proximity to the largest urban area, the Malmo-Lund region, is more important than proximity to the other center *The effect of access to CR on residential house prices differs across market segments, with lower income groups benefiting more than richer.
He (2020)	Mass transit railway (MTR)	3 regions in Hong-Kong	-	-	-	R	167,297	2001-2011	DID	*+ 10% in the accessibility to MTR => + 3.52% in residential prices in 2001 and +4.73% in 2011. *Various local effects in the 59 submarkets.

Prop. = Property-ies; LR = light rail, HR = heavy rail, CR = commuter rail, HSR = high-speed rail;
MA = metropolitan area; L = Land, C= commercial properties, R= residential properties;
OLS = Ordinary Least Square, DID =difference-in-differences

Source: Authors

All in all, the studies confirm the significant accessibility effect of commuter rail (an increase in properties values ranging from +2.7% to +20% compared with properties without a commuter rail station in the neighborhood). The significant radii of influence of a commuter rail station vary from 0 to 3 miles (Bowes and Ihlandfeldt 2001; Amstrong and Rodriguez 2006; Debrezion et al. 2007; Dubé et al. 2013; Mohammad et al. 2013; He 2020). In Los Angeles County however, this influence differs according to the commuter railway line under consideration (Cervero and Duncan 2002b). Indeed, housing submarkets are frequently emphasized in hedonic studies that may affect the accessibility effect (Debrezion et al. 2011; He 2020). Disamenities from being too close from a station are also emphasized in the seminal paper of Bowes and Ihlanfeldt (2001). On the other side, certain workplaces appear to be more attractive than others in the eyes of house purchasers, as revealed in Bohman and Nilsson (2016) in Scania Region, Sweden.

In most studies, the effect of commuter rail accessibility is revealed as higher than light rail accessibility (Cervero 2002a, 2006; Debrezion et al. 2007; Mohammad et al. 2013). The method retained for accessibility measurement may vary across studies: shortest distance, shortest travel time to the station walking, cycling or by car (Debrezion et al. 2011; Dubé et al. 2013; He 2020). The level of rail service proposed may also influence the choice of the preferred station by the commuters (Debrezion et al. 2011). Last, regional outcomes emphasize a generally higher rail impact in Asian and European metropolitan areas compared with North American, which are assumed to be more car-oriented (Mohammad et al. 2013; He 2020).

3. Material and methods

This section describes our methodological strategy to explain the formation of residential land values, given the two types of areas under consideration, and the data we use. We use hedonic pricing and estimate the effects of commuter rail accessibility on residential land values.

3.1. The Loire-Atlantique Département

Loire-Atlantique is one of the 101 French *Départements*, an administrative unit located between the 1254 urban communities in France (as of January 1st, 2020) and the 13 *Régions*. Loire-Atlantique is

located in the West of France, at the edge of the Atlantic Ocean. It had 1.43 million inhabitants on January 1st, 2017, with 640,000 living in the conurbation of Nantes *Métropole*, located 380 km from Paris. The annual population growth rate in L.A. was 1.3% between 2011 and 2016, three times higher than the national rate (of 0.4% per year).

The metropolitan area of Nantes is constituted by (1) the central city of Nantes (310,000 inhabitants), (2) the 23 suburban municipalities of the conurbation of Nantes *Métropole* (330,000 inhabitants) and (3) the municipalities located around the conurbation and attracted by Nantes *Métropole* (310,000 inhabitants). The municipalities non-attracted by Nantes *Métropole* are considered as remote areas: they have 470,000 inhabitants. The land transactions we consider here come from the two last types of areas (Figure 1).

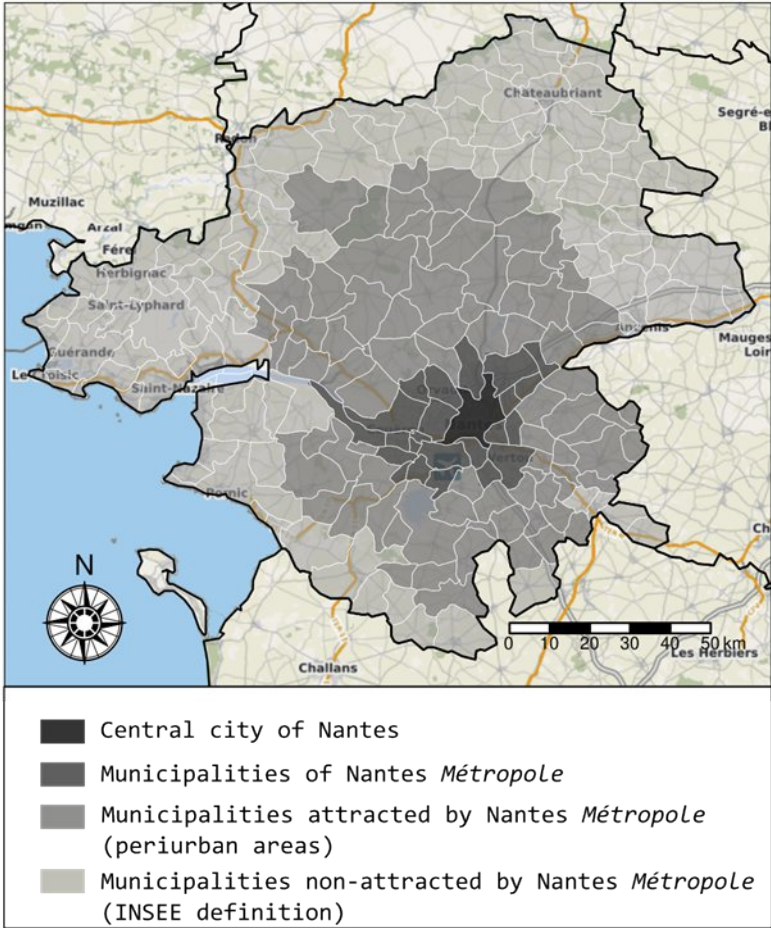


Fig. 1 The four types of areas in the Loire-Atlantique Département, according to the simplified INSEE definitions

Source: Authors

To distinguish between attracted and non-attracted municipalities, we use the 2010 INSEE definition. The peri-urban areas (located between the conurbation of Nantes *Métropole* and the remote areas) consisting in municipalities in which at least 40% of the active inhabitants commute to one of the municipalities constituting the conurbation of Nantes *Métropole*. In the remote areas or municipalities ‘not attracted’ by Nantes *Métropole*, under 40% of commuters are found.

3.2. Database construction

The data on residential land values come from the Perval database for land transactions recorded in 2012 in both the peri-urban area of Nantes (of which we retain 431 observations) and remote areas of the L.A. *Département* (395 observations retained). The Perval database includes the intrinsic characteristics of the plot (surface area, access to a public road, utility connections, presence of buildings to be demolished), the nature of the seller and the purchaser (individual or legal entity), and the nature of the transaction (ownership status, nature of land transfer).

Some of the observations in the initial database were not retained, for the following reasons:

- The absence of possibility of utility connections due to the distance of the plot from the various networks: water, gas, electricity, sanitation.
- The legal context: transactions located in agricultural or natural zones, plots in building areas but not intended for housing, certain particular types of land transfer (inheritances, sequestrations), and the occupation of the plot by a third party.
- The nature of the purchaser: firm or administration.

We include contextual variables (accessibility and neighborhood) in the database that are likely to influence the plot price for each land transaction:

- The distance to the nearest commuter rail station, which is our variable of interest;
- The distance to the closest amenity (food stores, and primary and secondary schools). This data comes from the Permanent Equipment Base of INSEE (BPE 2012);
- The distance to the coast, in 4 classes: <1 km, 1-5 km, 5-15 km and > 15 km;

- The unemployment rate (in 2012) in the municipality where the plot is located, given by INSEE.
- The population density (in 2012) of the administrative unit where the plot is located. The census unit scale selected here is the IRIS (acronym for “Aggregated Units for Statistical Information”), representing the smallest unit for dissemination of French infra-municipal data (which merges with the municipal unit in the case of small rural municipalities). Data are provided by INSEE.

All distances are measured as the crow flies. We used the open data portal supplied by the Pays de la Loire *Région*, which is the upper level of local government to which the L.A. *Département* is attached, with four other *Départements*. We considered 55 commuter rail stations in the L.A. *Département*. Although we did not look at transactions in the conurbation of Nantes *Métropole* regarding the relationship between proximity to a commuter rail station and residential land values, we did keep the corresponding urban stations in order to avoid edge effects when considering transactions close to Nantes *Métropole* in the peri-urban area. All of these 55 stations were in service for mobility users in 2012, with the exception, in the North of the *Département*, of the eight stations of the *tram-train* line between Châteaubriant and Nantes. This particular transport offer can be considered as commuter rail given the level of service provided. It was launched in February 2014. However, as it was announced in 2010, we expect anticipation effects in purchases of land next to this railway line.

The descriptive statistics of the data appear in Table 2.

Table 2. Descriptive statistics

Variables	Mean or % (std)
Dependent variable	
Plot price (€)	73,225 (39,710)
Intrinsic variables	
Plot size (m ²)	735.6 (545.9)
Land with utility connections (%)	60.0
Commuter rail station related variables	
Distance to the nearest station (%)	
< 1km	14.0
[1:5km]	26.4
[5:15km]	51.2
> 15km	8.4
Min. travel time to Nantes city center (mn)	29.8 (16.7)
Number of passengers at the station (mean per day)	704 (780)
Contextual variables	
Located in the peri-urban area of Nantes <i>Métropole</i> (% Yes)	47.5
Distance to the coast (%)	
< 1km	8.3
[1:5km]	10.5
[5:15km]	16.0
> 15km	65.2
Distance to the nearest food store (km)	2.5 (2.1)
Distance to the nearest primary or secondary school (km)	1.4 (1.1)
Unemployment rate (%)	8.8 (2.5)
Population density (inhab. per hectare)	2.5 (4.3)

Source: Authors

3.3. Statistical analyses

In order to explore the relationship between residential land values and commuter rail accessibility (quantified as the distance to the nearest station) while controlling for intrinsic and contextual variables, we based our analysis strategy on two steps. (i) The first one consists in estimating an aspatial parametric model (Ordinary Least Square or OLS) to capture the average effect of commuter rail accessibility over the entire study area. (ii) In a second step, we computed a multiscale geographically

weighted regression (MGWR) to explore the spatial heterogeneity of the studied relationship. Our methodological procedures are described in detail below.

The adjusted average effect of the discretized distance to the nearest commuter rail station on the plot price was estimated using a global log-linear model of the following form:

$$\ln(Y) = \beta_0 + \sum_{i=1}^N \beta_i x_i + \varepsilon_i \quad (1)$$

where Y is the dependent variable (the plot price), x_i a vector of explanatory variables, β_i a vector of parameters to be estimated, β_0 an intercept term and ε_i a residual error term. However, since the effect of the distance to the nearest commuter rail station is assumed to be non-linear and characterized by threshold effects (Cavailhès 2005; Travers et al. 2008; Brécard et al. 2018), we previously discretized the distance following the outputs of a generalized additive model (GAM). GAM is a type of nonparametric model estimating the relationship between a response variable and a predictor as nonlinear functions in a multiple-regression framework (Hastie and Tibshirani 1990; von Graevenitz and Panduro 2015; Wood 2017). The method allows statistical relationships to be described by smooth curves (usually splines) in a highly-flexible way (see Wood 2017, for a mathematical description of the model). Our models are of the following form:

$$E(Y) = g^{-1} \left(\beta_0 + \sum_{j=1}^J f_j(x_j) \right) \quad (2)$$

where $E(Y)$ is the expected value of the response Y (with an appropriate distribution and link function g), f_j is a smooth function of the covariate x_j , β_0 is an intercept term and g^{-1} is the inverse link function. Here, the GAM model estimates a nonlinear relationship between the plot price (log-transformed) and the distance to the nearest commuter rail station, controlling for all of the other covariates (without smoothing). Thin plate regression splines were used as smoothers, while the smoothing parameter was selected using restricted maximum likelihood, following the recommendation of Pedersen et al. (2019). First derivatives were then calculated on the fitted GAM smoothing function to get slope changing thresholds. Three thresholds were thus identified and were finally used to discretize the distance to the nearest commuter rail station. After identifying heteroskedasticity via the Breusch-Pagan

test, the Huber-White method was used to estimate robust standard errors of the regression coefficients.

In a second step, we explored the possibility of spatial heterogeneity of the relationship between the plot price and the distance to commuter rail station by computing a MGWR. The underlying assumption is that this relationship likely varies according to the local context, including the attractiveness of the municipality where the nearest station is located. GWR is a local modelling method that explicitly considers spatial context by allowing the coefficients to vary over space (Brunsdon et al. 1996; Fotheringham et al. 2003; Feuillet et al. 2018). GWR fits a local regression at each observation based only on the characteristics of neighboring observations, using a distance-based weighting scheme. We used an exponential weighting function with an adaptive kernel (i.e. a nearest-neighbor measure of proximity), which is recommended in case of irregular spatial observations (Feuillet et al. 2015). The model is expressed as follows (Brunsdon et al. 1996):

$$y_i = \beta_{0(i)}(u_i, v_i) + \sum_k \beta_{k(i)}(u_i, v_i) X_{k(i)} + \varepsilon_i \quad (3)$$

where $\beta_{k(i)}(u_i, v_i)$ are local model parameters associated with explanatory variables and specific to location i , with (u_i, v_i) representing the geographical coordinates of location i . and $X_{k(i)}$ is the value of the k^{th} variable at location i . Therefore, GWR computation allows the estimation of one regression coefficient by individual. The resulting vectors of coefficients can then typically be used to map surfaces of statistical relationships, providing a powerful exploratory tool for spatial analyses.

A key point in GWR calibration relates to the choice of an optimal bandwidth, which corresponds, in the case of a nearest-neighbor-based spatial weighting scheme as used here, to the number of neighbors selected to define neighborhood. This choice affects the spatial weights assigned to observations, and then the estimates. In conventional GWR, the kernel-based spatial weighting matrix is typically based on a single optimal bandwidth for all the regressors (e.g. a single number of nearest-neighbors), resulting from an AIC minimization (Akaike Information Criterion) or a cross-validation procedure. A single bandwidth assumes that the data are weighted at the same spatial scale (Oshan et al. 2020), and that all the spatially varying parameters arise from processes operating at the same spatial scale

(Fotheringham et al., 2017). To overcome this limitation, Fotheringham et al. (2017) extended the method in relaxing this assumption, i.e. in allowing the conditional relationships between the outcome and the predictors to vary at different spatial scales. This extension, called MGWR (multiscale geographically weighted regression), reformulates GWR as follows:

$$y_i = \sum_{j=1}^k \beta_{bwj}(u_i, v_i) x_{ij} + \varepsilon_i \quad (4)$$

Where bw_j in β_{bwj} depicts the bandwidth used for calibration of the j^{th} conditional relationship (Fotheringham et al., 2017). To calibrate MGWR models, the authors suggest using backfitting algorithms, as commonly used for calibrating GAM. Fotheringham et al. (2017) explain that following the logic of GAM, the term $\beta_{bwj}x_{ij}$ of equation (4) should be defined as the j^{th} additive term f_j resulting in a GAM-style MGWR:

$$y = \sum_{j=1}^k f_j + \varepsilon \quad (5)$$

The backfitting procedure was calibrated using a differential version of the changing value of residual sum of squares (RSS), as defined in Lu et al. (2017):

$$CVR^{(k)} = \frac{RSS^{(k)} - RSS^{(k-1)}}{RSS^{(k-1)}} \quad (6)$$

Thus, a set of optimal covariate-specific bandwidths was estimated following this procedure.

Finally, we grouped together the transactions with comparable coefficient values, in order to see in which municipalities they were located, and to emphasize potential differences between peri-urban and remote areas. If these exhibit different correlations of residential land values with commuter rail stations, then the appropriate transport policies will likely vary spatially as well. All of the analyses were carried out in R (R Development Core Team 2015), with the ‘mgcv’ (Wood 2017) and ‘Gw-model’ (Gollini et al. 2015) packages being used to run GAM and MGWR respectively.

4. Results and discussion

The log-transformed price per square meter of the plot is the dependent variable. In a first step, we looked for a nonlinear relationship between the distance to the nearest commuter rail station and residential land values using a GAM regression, in order to relevantly discretized this distance in the subsequent OLS model. First derivatives of the fitted GAM function highlighted three slope changing thresholds: 2.8 km, 5.6 km and 16 km (Figure 2).

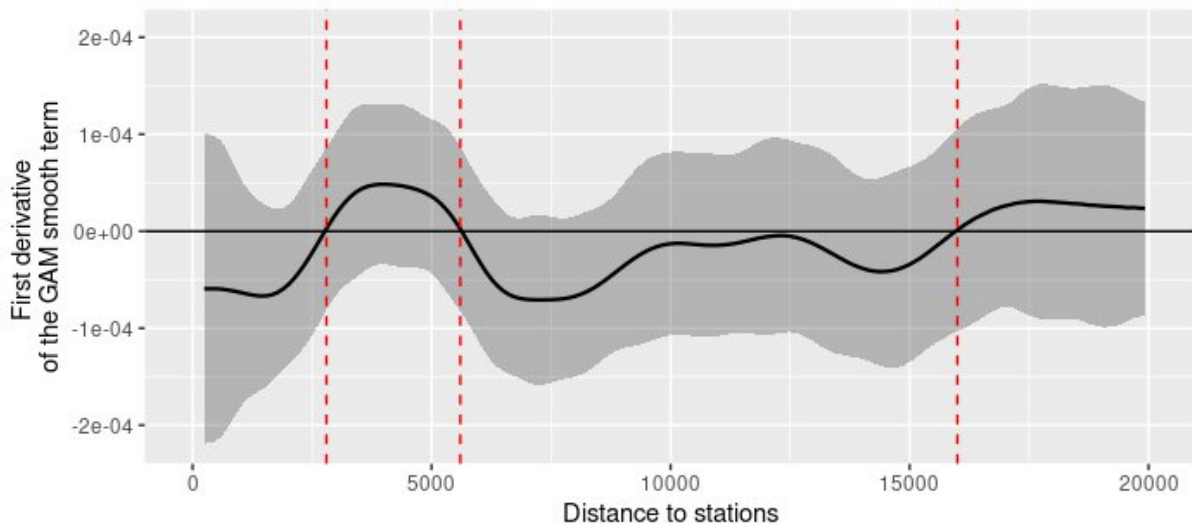


Fig. 2 First derivatives of the fitted Generalized Additive Model (GAM) function, modelling the relationship between the distance to the nearest commuter rail station and plot prices

Source: Authors

In a second step, we estimated an OLS regression, considering discrete groups of our variable of interest, the distance to the nearest commuter rail station. Multicollinearity was previously checked using VIF index (Variance Inflation Factor) for all of the explanatory variables (< 2). The estimated coefficients on distance in a land-price regression are significant (Table 3).

Table 3. OLS results for the price per square meter of the plot (peri-urban and remote areas)

<i>Variables</i>	<i>Estimate</i>	<i>r.s.e.</i>	<i>t-value</i>	<i>p-value</i>
(Intercept)	11.67	0.11	102.65	<0.001
<i>Intrinsic variables</i>				
Plot size (<i>m</i> ²)	0.34***	0.02	14.33	<0.001
Land without utility connections	-0.08**	0.03	-2.98	<0.001
<i>Railway-station related variables</i>				
Distance to the nearest station (<i>ref</i> = >16km)				
< 2.8km	0.17***	0.06	2.83	0.001
[2.8:5.6km]	0.12	0.06	1.94	0.05
[5.6:16km]	0.09	0.06	1.59	0.11
Min. travel time to Nantes city center (<i>mn</i>)	0.00	0.00	0.56	0.58
Number of passengers at the station (<i>mean per day</i>)	-0.00	0.00	-1.93	0.05
<i>Other contextual variables</i>				
Located in a remote area (<i>ref</i> =peri-urban)	-0.23***	0.03	-6.84	<0.001
Population density (<i>inhab. per hectare</i>)	0.02***	0.00	5.29	<0.001
Distance to the coast (<i>ref</i> = <1km)				
[1:5km]	-0.34***	0.06	-6.08	<0.001
[5:15km]	-0.78***	0.06	-13.68	<0.001
>15km	-0.90***	0.05	-16.60	<0.001
Distance to the nearest food store (<i>km</i>)	-0.05***	0.01	-7.69	<0.001
Unemployment rate (%)	-0.04***	0.01	-5.29	<0.001

Multiple R-squared = 0.468; Adjusted R-squared = 0.459. r.s.e = robust standard error

N=the 431+395 land transactions in 2012 in the peri-urban areas of Nantes *Métropole* and municipalities not attracted by Nantes *Métropole*. * Significant at the 5% level, ** Significant at the 1% level, *** Significant at the 0.1% level.

Source: Authors

Regarding the intrinsic variables, the plot size plays a major role in the price per square meter. The absence of utility connections on the plot is negatively correlated with the price.

OLS model also reveals that being located closer to a commuter rail station, relative to the reference category of over 16 km, leads to higher residential land values. The estimates rise as the distance to the station falls (from 0.09 for 5.6-16 km to 0.17 for <2.8 km), with a 1% significance level between 0 and 2.8km. This result is in line with some other hedonic studies in non-urban areas, whether involving land (e.g. Cervero and Ducan, 2002b) or housing values (e.g. Bulteau et al. 2018). Having a com-

muter rail station nearby in peri-urban and remote areas implies a significant gain in commuter rail accessibility, unlike in urban areas where it is frequently viewed as a disamenity (due to crime, noise etc.) and lowers house prices (Bowes and Ihlanfeldt 2001; Seo et al. 2014). Conversely, the station's number of daily passengers, which indicates the level of service provided by the station, does not significantly affect residential land values. This is also the case of the 'min. travel time to Nantes' variable. This absence of relationship is probably due to the lack of consideration of certain qualitative attributes in this study, such as comfort when traveling. Moreover, this variable exhibits a low variance that in turn could explain the absence of significant relationship. Indeed, the range of travel times between the commuter rail station under consideration and the station in Nantes is ultimately limited given the short distances to be covered. In other words, the minimum travel time to the central city of Nantes may not be, overall, a decisive variable for travelers at this geographic scale.

Regarding the other contextual variables, the population density in the municipality of residence positively influences land values. On the other hand, the estimated coefficient on the dummy for the plot being in a remote area suggests a lower price per square meter there than for plots in peri-urban areas. This confirms the attraction of the conurbation of Nantes *Métropole* in peri-urban areas, as defined by INSEE. Proximity to the sea also produces higher residential land values, in line with other French work (Travers et al. 2008; Dachary-Bernard et al. 2011). The same result is found for proximity to food facilities, as in the literature (Jang and Kang 2015; Wu et al. 2017; Ay et al. 2018). Wu et al. (2017) show that the proximity to the nearest supermarket has a positive effect on house prices. This is an important criterion for land buyers, as the mean distance to shops, among other amenities, is higher in peri-urban and remote areas than conurbations (Barbier et al. 2016). The unemployment rate in the municipality reduces residential land values in peri-urban and remote areas. Similar results are found in French work on medium- and low-density areas (Michalland and Vollet 1999; Bulteau et al. 2018), in research on tourist areas in Spain (Perles Ribes et al. 2018), and in Chinese urban data (Wang et al. 2011). Whatever the location (in urban, peri-urban or remote areas), unemployment seems to be associated with lower house and land values.

Last, we estimated a MGWR to produce a local analysis that may refine the global results regarding the role of commuter rail accessibility on residential land values (Figure 3).

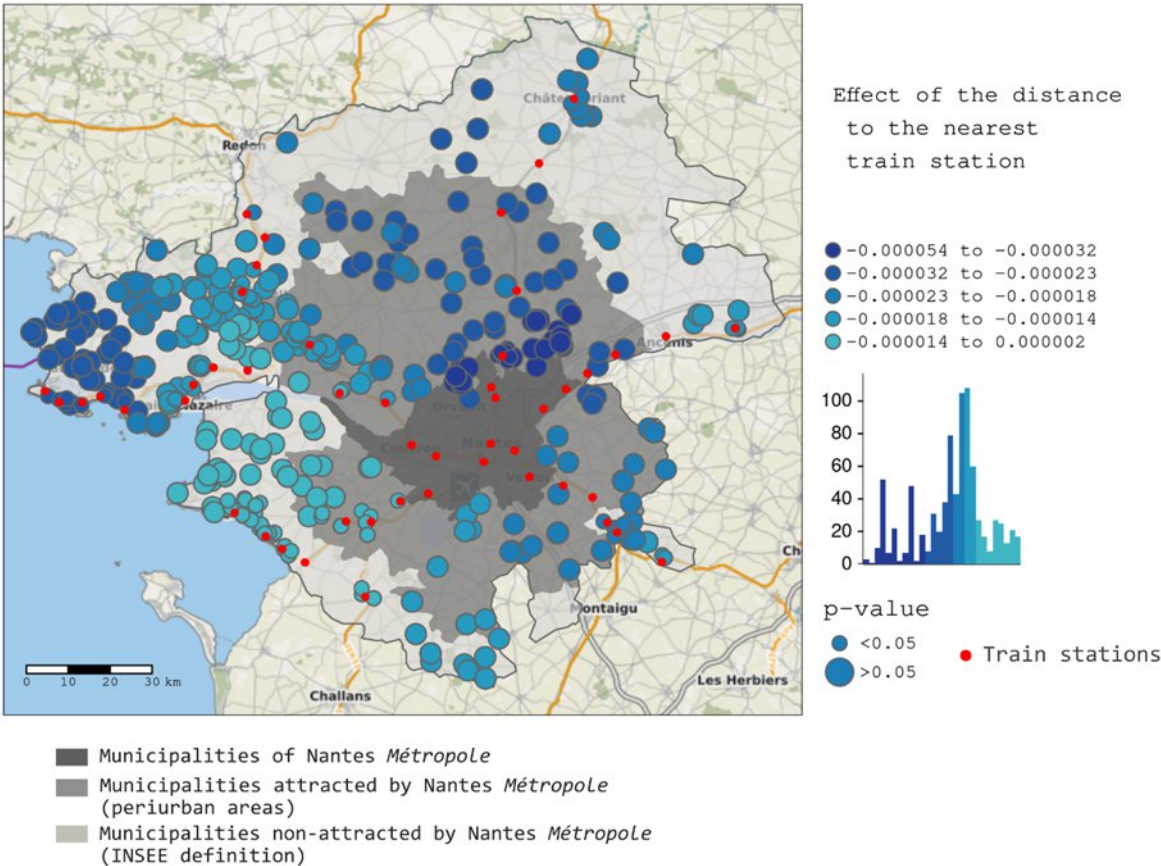


Fig. 3 Map of MGWR coefficients representing the spatially-varying relationships between plot prices (log-transformed) and the distance to the nearest commuter rail station, adjusted for the covariates

Notes: Multiple R-squared = 0.682; Adjusted R-squared = 0.643. The 55 commuter rail stations appear in red.

Source: Authors

The backfitting procedure yielded to an optimal bandwidth of 55 neighbors for the parameters associated with the distance to the nearest commuter rail station. Other bandwidths ranged from 44 to 217 neighbors. The results for the Loire-Atlantique *Département* are striking. The map of the MGWR coefficients revealed spatial non-stationarity, i.e. spatial heterogeneity of relationships between commuter rail accessibility and residential land values. First, in the Northern area close to Nantes *Métropole* (a peri-urban area), the proximity of a commuter rail station is strongly associated with higher residential land values. In this part of the (nearby) peri-urban areas, railway lines represent an effective quasi-urban network towards Nantes city center, with the additional benefit of serving com-

muter rail stations within the conurbation. In this particular area, this benefit in the eyes of land purchasers may be interpreted as an anticipation effect of the *tram-train* line that was launched in the North of the L.A. *Département* in 2014, combined with the benefits being close to the conurbation of Nantes *Métropole*. Bulteau et al. (2018) found a comparable result for commuter railway accessibility (i.e. being located near a commuter rail station of the Châteaubriant-Nantes line (North) significantly improves overall accessibility to Nantes).

Second, there is also a strong positive relationship between commuter rail stations and residential land values in the Western part of the *Département* (a remote area in the sense of ‘not attracted’ by Nantes *Métropole*). In this area, the travel times using the train from Le Croisic to Nantes are competitive compared to the use of a private car, with five intermediate commuter rail stations available for travelers. This result holds both for plots designated for primary-occupancy housing (so that the regional train – the *Train Express Régional* or TER – is mainly used for commuting to Nantes) and second homes, where the high-speed rail line from Paris (*Train à Grande Vitesse* or TGV) may be viewed as an advantage for tourists. These are two very segmented uses of railway lines, which are often at odds with each other in France, regarding public spending (daily commuting vs. occasional high-speed rail). This segmentation may help guide the priorities regarding rail stations in France in the future.

In a third and last group of municipalities, in the *Pays de Retz* (Southwest of the L.A. *Département*, in another remote area), the potential benefits of commuter rail stations in residential land values is weaker, in spite of the presence of two railway lines (Pornic/ Nantes and Saint-Gilles-Croix-de-Vie/ Nantes). These two were among the five older railway lines in France that were not renovated in 2012 (with five stations being concerned). It is still of interest to note that commuter rail stations on the same line but closer to the conurbation of Nantes *Métropole* are more attractive to land buyers given the lower travel times they expect. To sum up these results, commuter rail accessibility seems to be viewed as effective in that rail transit is either competitive in terms of travel times relative to cars (in remote areas) or provide easy access to the urban transit network (in nearby peri-urban areas of Nantes *Métropole*). The latter is attractive for land buyers in terms of frequency of the service, connections to other transport modes and opening hours.

Such a spatial heterogeneity of relationships has already been reported. For instance, Bulteau et al. (2018) revealed a strong territorial heterogeneity: within the conurbation of Nantes *Métropole*, proximity to alternative offers to private car has a direct and mainly positive impact on house prices, whereas in peri-urban areas this effect is either minor or nonexistent. Moreover, using a GWR, the authors highlighted comparable results on house prices for the Northern part of the L.A. *Département*, with considerable interest among buyers in the *tram-train* line from Châteaubriant to Nantes. Many other studies confirm the presence of spatial heterogeneity in the relationships between rail accessibility and property values elsewhere. From the Tyne and Wear case study, UK, Du and Mulley (2006) highlighted that the relationship between transport accessibility to bus and light rail stations and land value is fairly complicated and greatly varied over space, an issue that was clearly addressed by the use of GWR. Using a two-stage spatial quantile regression, Bohman and Nilsson (2016) also reported an effect of access to commuter rail on residential house prices that differs across market segments in Scania region, Sweden. In Los Angeles, US, spatial variations patterns among various corridors revealed by a GWR indicate heterogeneous accessibility to heavy rail stations related to safety levels, built-environment features around the stations, and the property type: single or multiple-family houses (Zhong and Li, 2016). In Honk Kong, a gravity-based accessibility measure revealed local variations of commuter rail accessibility effect among the 59 submarkets under study (He 2020). Using a multilevel model, Arum and Fukuda (2020) found that railway lines with the highest effects are located around south to west of Tokyo, Japan. This might be related to the history of urban planning in Tokyo, where suburban expansion was planned and these areas were among the first areas to be developed. In Brisbane, Australia, Mulley et al. (2016) revealed through a GWR that the northern part of the study area sees accessibility premiums being close to a commuter rail station thanks to several passenger train routes that provide both more frequent services and large coverage. By contrast, southern and western rail routes provide significant (uncovered) coal train operations to the Port of Brisbane, providing night-time nuisance and pollution effects. Last, relying on a LCR GWR (Locally Compensated Ridge GWR), Li et al. (2021) found the greatest positive premiums of commuter rail accessibility in the south-east of Melbourne, Australia, whereas the negative premiums that are found in the Central Business District area are attributed to lower transport cost, and to noise and crowds around commuter

rail stations. All these results encourage to consider local contexts to fully capture the complexity of commuter rail accessibility effect on residential land values. The geography of this effect is likely to be spatially structured, driven by unobserved and complex factors that are typically difficult to quantify and to include in statistical models. GWR or other spatially varying coefficient models therefore appear particularly suited for exploring such local nuances.

5. Conclusions

This paper has investigated the relationships between the proximity to a commuter rail station and residential land values in peri-urban and remote areas of the Loire-Atlantique *Département* in France. As we expected a nonlinear relationship, we first computed a Generalized Additive Model (GAM) that confirmed this hypothesis. We then ran an Ordinary Least Square (OLS) regression of residential land values in the area considered using GAM-derived thresholds to discretize the distance to the nearest commuter rail station. Last, we estimated a multiscale geographically weighted regression (MGWR) to test for heterogeneity between local contexts when considering commuter rail accessibility.

We have a number of original results. Being close to the conurbation of *Nantes Métropole* (in the peri-urban area) seems to be viewed positively, as land purchasers likely value better access to the urban transport network as an anticipation effect, among other factors. However, if we look at the actual property values after the opening of the Nantes-Châteaubriant line, we note that in 2015 prices rose by nearly 20% for the municipality that benefits from a commuter rail station (Sucé-sur-Erdre), whereas price changes for two other neighboring municipalities with more than 5,000 inhabitants, also close to the conurbation of *Nantes Métropole* but not served by a commuter rail station are much lower, even negative. It could therefore be hypothesized that the anticipation effect noted in 2012 in Sucé-sur-Erdre had not yet fully resulted in land capitalization before the line opened. In the Western part of the *Département* (a remote area), residential land values are also positively associated with proximity to a commuter rail station, where both commuters and tourists can benefit from the high-speed rail service towards Nantes. This is however not the case in the South-Western part of the L.A. *Département* (an-

other remote area), where the quality of rail service was regarded as poor at the time our land transactions were recorded.

Our results provide some new insights for policy makers in peri-urban and remote areas. Our recommendations are for the development of local mobility systems, following the results from the MGWR. The positive relationship between commuter rail station proximity and residential land values should encourage decision-makers to help these stations evolve into multimodal exchange poles: this could be the case in the Northern part of the *Département*. Conversely, in the case of weak or non-significant influence of the station (in the Southern and Eastern parts of the *Département*), incentives to encourage carpooling for complete origin-destination journeys could be pushed by local authorities: this may also be the case in the South-Western part of the *Département*, even if the two railway lines were renovated after 2012 and nowadays provide a better-quality service, especially in terms of travel times.

Our work has also some limitations. First of all, due to the cross-sectional nature of the data we have the well-known inference-causality problem. Second, some omitted contextual variables may have affected our results (for example, the level of criminality in the municipality). Third, our sample (826 observations) presents the classical statistical drawbacks of small samples. In particular, one should be cautious about the conclusions drawn on the verification of the usual properties of convergence of the predicted OLS estimator, whose variance decreases as the number of observations increases (Keita, 2015). Our conclusions would thus appear more robust with a larger sample size. Last, our field of study covers only a limited geographical area, so that our results may not be reproducible in other or larger areas. For these reasons, our results in general should be interpreted with caution.

Despite this caution, the range of our results regarding the types of areas considered may still help decision-makers to prepare tomorrow's autonomous modes of transport to complement railway offers for commuting trips. This confirms the need for local authorities to anticipate as of today expensive infrastructure for autonomous shuttles to ensure first/last-mile trips towards/ from commuter rail stations. The latter are being envisaged by many French municipalities, as the ability of mobility suppliers to provide automated driving progressively increases. A number of current tests of the technical viability

of this concept in urban areas are being carried out. This opens the way to further work in peri-urban and remote areas combining hedonic pricing with MGWR. More generally, the dynamics of anticipation effects are instructive for transport accessibility studies and would merit further analysis.

References

Alonso W (1964) Location and land use

Andersson DE, Shyr OF, Lee A (2012) The successes and failures of a key transportation link: accessibility effects of Taiwan's high-speed rail. *The Annals of regional science*, 48(1), 203-223

Arum SP, Fukuda D (2020). The impact of railway networks on residential land values within transit-oriented development areas. *Asian Transport Studies*, 6, 100009

Ay JS, Cavailhès J, Hilal M, Le Gallo J (2018) Does issuing building permits reduce the cost of land? An estimation based on the demand for building land in France. *Economie et Statistique*, 500(1), 45-67

Barbier M, Toutin G, Levy D (2016) L'accès aux services, une question de densité des territoires. INSEE Report, 4 pages

Bohman H, Nilsson D (2016) The impact of regional commuter trains on property values: Price segments and income. *Journal of Transport Geography*, 56, 102-109

Bowes DR, Ihlanfeldt KR (2001) Identifying the impacts of rail transit stations on residential property values. *Journal of urban Economics*, 50(1), 1-25

Brécard D, Le Boennec R., Salladarré F (2018) Accessibility, local pollution and housing prices. Evidence from Nantes Métropole, France. *Economie et Statistique* 500, 97-115

Brueckner JK (2011) *Lectures on Urban Economics*. MIT Press

Brunsdon C, Fotheringham AS, Charlton ME (1996) Geographically weighted regression: a method for exploring spatial nonstationarity. *Geographical Analysis* 28(4), 281-298

- Bulteau J (2012) Tradable emission permit system for urban motorists: The neo-classical standard model revisited. *Research in Transportation Economics* 36(1), 101-109
- Bulteau J (2016). Revisiting the bottleneck congestion model by considering environmental costs and a modal policy. *International Journal of Sustainable Transportation* 10(3), 180-192
- Bulteau J, Feuillet T, Le Boennec R (2018) Spatial Heterogeneity of Sustainable Transportation Offer Values: A Comparative Analysis of Nantes Urban and Periurban/Rural Areas (France). *Urban Science* 2(1), 14
- Cao J, Cao X (2014) The impacts of LRT, neighbourhood characteristics, and self-selection on auto ownership: Evidence from Minneapolis-St. Paul. *Urban Studies* 51(10), 2068-2087
- Cao X, Mokhtarian PL, Handy SL (2009) Examining the impacts of residential self-selection on travel behaviour: a focus on empirical findings. *Transport Reviews* 29(3), 359-395
- Cavailhès J (2005) Le prix des attributs du logement. *Economie et statistique* 381(1), 91-123
- Cervero R (2002) Built environments and mode choice: toward a normative framework. *Transportation Research Part D : Transport and Environment* 7(4), 265-284
- Cervero R, Duncan M (2002a) Benefits of proximity to rail on housing markets: Experiences in Santa Clara County. *Journal of Public Transportation*, 5(1), 3
- Cervero R, Duncan M (2002b) Land value impacts of rail transit services in Los Angeles County. *Report prepared for National Association of Realtors Urban Land Institute*
- Cervero R (2006) Effects of light and commuter rail transit on land prices: Experiences in San Diego County
- Chalermpong S (2007) Rail transit and residential land use in developing countries: hedonic study of residential property prices in Bangkok, Thailand. *Transportation Research Record*, 2038(1), 111-119

- Chen Z, Haynes KE (2015) Impact of high speed rail on housing values: An observation from the Beijing–Shanghai line. *Journal of Transport Geography* 43, 91-100
- Cho SH, Bowker JM, Park WM (2006) Measuring the contribution of water and green space amenities to housing values: An application and comparison of spatially weighted hedonic models. *Journal of agricultural and resource economics*, 485-507
- Clark WA, Onaka JL (1983) Life cycle and housing adjustment as explanations of residential mobility. *Urban Studies* 20(1), 47-57
- Czembrowski P, Kronenberg J (2016) Hedonic pricing and different urban green space types and sizes: Insights into the discussion on valuing ecosystem services. *Landscape and Urban Planning*, 146, 11-19
- Dachary-Bernard J, Gaschet F, Lyser S, Pouyanne G, Virol S (2011) L’impact de la littoralisation sur les marchés fonciers : une approche comparative des côtes basque et charentaise. *Economie et Statistique/Economics and Statistics* 444-445, 127-154
- Davis MA, Palumbo MG (2008) The price of residential land in large US cities. *Journal of Urban Economics* 63(1), 352-384
- Debrezion G, Pels E, 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(2), 161-180
- Debrezion G, Pels E, Rietveld P (2011) The impact of rail transport on real estate prices: an empirical analysis of the Dutch housing market. *Urban Studies*, 48(5), 997-1015
- Devaux N, Dubé J, Apparicio P (2017) Anticipation and post-construction impact of a metro extension on residential values: The case of Laval (Canada), 1995–2013. *Journal of Transport Geography* 62, 8-19
- Du H, Mulley C (2006) Relationship between transport accessibility and land value: Local model approach with geographically weighted regression. *Transportation Research Record*, 1977(1), 197-205

- Dubé J, Thériault M, Des Rosiers F (2013) Commuter rail accessibility and house values: The case of the Montreal South Shore, Canada, 1992–2009. *Transportation Research Part A: Policy and Practice*, 54, 49-66
- Dziauddin MF (2019) Estimating land value uplift around light rail transit stations in Greater Kuala Lumpur: An empirical study based on geographically weighted regression (GWR). *Research in Transportation Economics*, 74, 10-20
- Feuillet T, Charreire H, Menai M, Salze P, Simon C, Dugas J, Hercberg S, Andreeva VA, Enaud C, Weber C, Oppert JM (2015) Spatial heterogeneity of the relationships between environmental characteristics and active commuting: towards a locally varying social ecological model. *International Journal of Health Geographics*, 14
- Feuillet T, Commenges H, Menai M, Salze P, Perchoux C, Reuillon R, Kesse-Guyot E, Enaud C, Nazare JA, Hercberg S, Simon C, Charreire H, Oppert JM (2018) A massive geographically weighted regression model of walking-environment relationships. *Journal of Transport Geography* 68, 118-129
- Fotheringham AS, Brunson C, Charlton M (2003) *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. John Wiley & Sons
- Fotheringham AS, Yang W, Kang W (2017) Multiscale Geographically Weighted Regression (MGWR). *Annals of the American Association of Geographers* 107, 1247–1265
- Fujita M (1989) *Urban Economic Theory: Land Use and City Size*. Cambridge University Press
- Gollini I, Lu B, Charlton M, Brunson C, Harris P (2015) Gwmodel: An R Package for Exploring Spatial Heterogeneity Using Geographically Weighted Models. *Journal of Statistical Software* 63(17), 1-50
- Hastie T, Tibshirani R (1990) Exploring the nature of covariate effects in the proportional hazards model. *Biometrics*, 1005-1016

He SY (2020) Regional impact of rail network accessibility on residential property price: Modelling spatial heterogeneous capitalisation effects in Hong Kong. *Transportation Research Part A: Policy and Practice*, 135, 244-263

Hess DB, Almeida TM (2007) Impact of proximity to light rail rapid transit on station-area property values in Buffalo, New York. *Urban studies*, 44(5-6), 1041-1068

Jang M, Kang CD (2015) Retail accessibility and proximity effects on housing prices in Seoul, Korea: A retail type and housing submarket approach. *Habitat International* 49, 516-528

Kanemoto Y (1980) Theories of Urban Externalities

Katranji M, Kraiem S, Moalic L, Sanmarty G, Khodabandelou G, Caminada A, Selem FH (2020) Deep multi-task learning for individuals origin–destination matrices estimation from census data. *Data Mining and Knowledge Discovery*, 34(1), 201-230

Keita M (2015) Introduction à l'économétrie. MPRA Paper n°66840 [¶](#)

Kong F, Yin H, Nakagoshi N (2007) Using GIS and landscape metrics in the hedonic price modeling of the amenity value of urban green space: A case study in Jinan City, China. *Landscape and urban planning*, 79(3-4), 240-252

Kuminoff NV, Pope JC (2013) The value of residential land and structures during the great housing boom and bust. *Land Economics* 89(1), 1-29

Kyttä M, Broberg A, Haybatollahi M, Schmidt-Thomé K (2016) Urban happiness: context-sensitive study of the social sustainability of urban settings. *Environment and Planning B: Planning and Design* 43(1), 34-57

Le Boennec R (2014) Externalité de pollution versus économies d'agglomération : le péage urbain, un instrument environnemental adapté?. *Revue d'Économie Régionale & Urbaine* (1), 3-31

Le Boennec R, Sari F (2015) Nouvelles centralités, choix modal et politiques de déplacements : le cas nantais. *Les Cahiers Scientifiques du Transport* 67, 55–86 [¶](#)

- Le Boennec R, Lucas S (2021) Is neighborhood satisfaction related to density perception? Promoting liveable and sustainable land use planning. *Journal of Environmental Planning and Management*, 1-18
- Li Q, Wang J, Callanan J, Lu B, Guo Z (2021) The spatial varying relationship between services of the train network and residential property values in Melbourne, Australia. *Urban Studies*, 58(2), 335-354
- Lu B, Brunsdon C, Charlton M, Harris P (2017) Geographically weighted regression with parameter-specific distance metrics. *International Journal of Geographical Information Science* 31, 982–998
- Lund H (2006) Reasons for living in a transit-oriented development, and associated transit use. *Journal of the American Planning Association* 72(3), 357-366
- Mayor K, Lyons S, Duffy D, Tol RS (2012) A hedonic analysis of the value of rail transport in the Greater Dublin area. *Journal of Transport Economics and Policy (JTEP)*, 46(2), 239-261
- Michalland B, Vollet D (1999) Utilisation de la méthode des prix hédonistes pour l'évaluation des aménités agricoles et forestières : Etat des lieux et données disponibles. *Cahiers d'Economie et de Sociologie Rurales (CESR)* 51(905-2016-70471), 41-64
- Mohammad SI, Graham DJ, Melo PC, Anderson RJ (2013) A meta-analysis of the impact of rail projects on land and property values. *Transportation Research Part A: Policy and Practice*, 50, 158-170
- Mulley C, Ma L, Clifton G, Yen B, Burke M (2016) Residential property value impacts of proximity to transport infrastructure: An investigation of bus rapid transit and heavy rail networks in Brisbane, Australia. *Journal of Transport Geography*, 54, 41-52
- Nowok B, Findlay A, McCollum D (2018) Linking residential relocation desires and behaviour with life domain satisfaction. *Urban Studies* 55(4), 870-890
- Oikarinen E (2014) Is urban land price adjustment more sluggish than housing price adjustment? Empirical evidence. *Urban Studies* 51(8), 1686-1706
- Oshan TM, Smith JP, Fotheringham AS (2020) Targeting the spatial context of obesity determinants via multiscale geographically weighted regression. *Int J Health Geogr*, 19

- Pedersen EJ, Miller DL, Simpson GL, Ross N (2019). Hierarchical generalized additive models in ecology: an introduction with mgcv. *PeerJ* 7, e6876
- Perles Ribes J, Moreno Izquierdo L, Ramón Rodríguez A, Such Devesa M (2018) The rental prices of the apartments under the new tourist environment: A hedonic price model applied to the Spanish sun-and-beach destinations. *Economies* 6(2), 23
- R Development Core Team (2015) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna
- Rabe B, Taylor M (2010) Residential mobility, quality of neighbourhood and life course events. *Journal of the Royal Statistical Society: Series A (Statistics in Society)* 173(3), 531-555
- Rosen S (1974) Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82(1), 34–55
- Scheiner J (2010) Interrelations between travel mode choice and trip distance: trends in Germany 1976–2002. *Journal of Transport Geography* 18(1),75-84
- Schwanen T, Mokhtarian PL (2005) What affects commute mode choice: neighborhood physical structure or preferences toward neighborhoods?. *Journal of transport geography* 13(1), 83-99
- Seo K, Golub A, Kuby M (2014) Combined impacts of highways and light rail transit on residential property values: A spatial hedonic price model for Phoenix, Arizona. *Journal of Transport Geography* 41, 53–62
- Tideman N, Plassmann F (2018) The effects of changes in land value on the value of buildings. *Regional Science and Urban Economics* 69, 69-76
- Travers M, Nassiri A, Appéré G, Bonnieux F (2008) Evaluation des bénéfices environnementaux par la méthode des prix hédonistes : une application au cas du littoral. *Economie et prevision* (4), 47-62
- Verhoef E (1996) The economics of regulating road transport. *Books*

- Verhoef E, Nijkamp P (2008) Urban environmental externalities, agglomeration forces, and the technological ‘deus ex machina’. *Environment and Planning A* 40(4), 928-947
- von Graevenitz K, Panduro TE (2015) An alternative to the standard spatial econometric approaches in hedonic house price models. *Land Economics* 91(2), 386-409
- Wang S, Yang Z, Liu H (2011) Impact of urban economic openness on real estate prices: Evidence from thirty-five cities in China. *China Economic Review* 22(1), 42-54
- Wood SN (2017) *Generalized Additive Models: An Introduction with R*. Chapman and Hall/CRC
- Wu C, Ye X, Du Q., Luo P (2017) Spatial effects of accessibility to parks on housing prices in Shenzhen, China. *Habitat International* 63, 45-54
- Ye R, Titheridge H (2017) Satisfaction with the commute: The role of travel mode choice, built environment and attitudes. *Transportation Research Part D: Transport and Environment* 52, 535-547 ¶
- Yu L (2021) Study on Treatment Effects and Spatial Spillover Effects of Beijing–Shanghai HSR on the cities along the line. *The Annals of Regional Science*, 1-25¶
- Zhong H, Li W (2016) Rail transit investment and property values: An old tale retold. *Transport Policy*, 51, 33-48
- Zhou J, Yang L, Li L (2018) The implications of high-speed rail for Chinese cities: Connectivity and accessibility. *Transportation Research Part A: Policy and Practice*, 116, 308-326