



# Bus stop, property price and land value tax: A multilevel hedonic analysis with quantile calibration



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## ABSTRACT

Based on a multilevel and quantile hedonic analysis regarding the local public bus system and the prices of residential properties in Cardiff, Wales, we find strong evidence to support two research hypotheses: (a) the number of bus stops within walking distance (300–1500 m) to a property is positively associated with the property's observed sale price, and (b) properties of higher market prices, compared with their cheaper counterparts, tend to benefit more from spatial proximity to the bus stop locations. Given these statistical findings, we argue that, land value tax (LVT), albeit a classic political idea dating back to the early 20th century, does have contemporary relevance and, with modern geographic information technologies, can be rigorously analysed and empirically justified with a view to actual implementation. Levying LVT will not only generate additional fiscal revenues to help finance the development and maintenance of local public infrastructures, but will also ensure a more just distribution of the economic welfare yielded by public investment.

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## Introduction

In recent years, the United Kingdom (UK) has witnessed a revival of public interests in land value tax (LVT).<sup>1</sup> The original idea of LVT dates back to George (1879), an American political economist, who, partly inspired by Smith (1863), posits that the value of land, ultimately, comes from the adjacent infrastructures and amenities invested by the whole community. Increments in land value due to public investment, thus, ought to be re-captured through LVT. The earliest political attempts to legislate LVT took place in the late Edwardian Britain (Short, 1997, Chapter 2). LVT was officially proposed in the 1909 finance bill (also known as “People’s Budget”), when David Lloyd George served as Chancellor of the Exchequer as a member of the governing Liberal party. However, the then Conservatives-dominated House of Lords, though passing the general budget in 1910, managed to veto the LVT proposal. A similar story happened later with the 1931 Finance Act, which contained

a LVT initiative passed by the ruling Labour party but was rejected again by the Tory government in 1934 (Wenzer, 2000). One of the latest efforts to seek legislation of LVT was in 2012 by Carolyn Lucas, a Green party member of the UK parliament (The UK Parliament, 2012).

Although LVT was never implemented in Britain, its traces can be observed in many other places around the world, such as in the cities of Pittsburgh and Harrisburg in the American State of Pennsylvania and a number of countries such as Australia, Denmark, Estonia, Russia, and New Zealand (Andelson, 2000; Bourassa, 1990; Dye and England, 2010; Wyatt, 1994). While the actual policy practice varies among these international cases, LVT has been increasingly justified as a way to finance the construction and maintenance of public transport infrastructures. The basic rationale remains quite the same as per George original (1879), that publicly invested transport network can promote the values of nearby privately owned land plots, given their improved accessibility. From a political economy perspective, this part of added land value, if substantiated, becomes a kind of positive externalities which can be offset or captured through LVT. Otherwise, general tax payers (who generate government revenues) are essentially subsidising landowners who “quietly” extract the values of public transport infrastructures. Making this free-ride problem even more pressing is the undersupply and underfunding of public transport in the

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<sup>1</sup> For the examples of Labour’s Land Value Campaign (<http://www.labourland.org/>) and the Liberal Democratic Party’s Action for Land Taxation and Economic Reform (<http://libdemsalter.org.uk/>).

present-day UK, which has resulted in a series of social exclusion issues, faced typically by the lower income population who have difficulties affording private transport (Lucas, 2006).

In this paper, we explore the viability of levying land value tax to finance the maintenance and development of local public transport infrastructures within a contemporary UK context. Our empirical study focuses on the public bus system owned by Cardiff city council in south Wales, which saw a £0.6 million funding cut in the financial year of 2012, leading to a second increase in bus fares since October 2011 (Wales Online, 2012). Employing a conventional ordinary least square (OLS) hedonic regression approach, we firstly examine the relations between the sale prices of circa 10,000 residential properties across 12 electoral wards in central Cardiff from 2000 to 2009 (see Fig. 2), and the number of bus stops within the radii of 300 m, 400 m, 500 m, 750 m, 1000 m and 1500 m of each property, based on the 2007 National Public Transport Access Nodes (NaPTAN) dataset (Department for Transport, 2007). We then further refine the OLS results, respectively, within a multilevel modelling (Jones and Bullen, 1994) and quantile regression framework (Koenker, 2005). Our multilevel analysis suggests the OLS estimates to be unbiased with respect to the influence of bus stop locations on the implicit land values of nearby properties. Likewise, our quantile bivariate post hoc tests confirm the overall robustness of the OLS outcomes. A policy implication of these statistical findings is to exercise a two-tier progressive local land value taxation scheme in helping Cardiff council finance the local bus system. Our estimation, based on the number of bus stops within a 1500 m radius of every individual property included in our sample data, suggests that, for a property priced below circa £195,000, every additional bus stop contributes to a circa 0.11% marginal increase in property price through land value betterment. The corresponding figure is 0.22% for a property in the second tier with a market price above £195,000.

The remainder of this paper is organised as follows. The next section “Land value tax: from Edwardian to contemporary Britain” reviews the literature on land value tax and the related planning practices, mainly within a UK context. This is followed by the design of this research in “Research design” section, which studies the case of Cardiff Bus, by following an OLS and multilevel hedonic regression approach supplemented by a quantile calibration. The data and model results are reported in sections “The case of Cardiff bus” and “Model results”, respectively, before the study’s policy implications are discussed in “Policy implications” section. The conclusions are summarised in “Conclusion and future research” section, alongside the directions of future research.

## Land value tax: from Edwardian to contemporary Britain

### *The Edwardians*

The latest global economic recession has forced many countries to cut public spending. This is particularly the case in the UK, with the coalition government aiming to reduce public expenditure by as much as £6.2 billion between 2010 and 2011 (Her Majesty’s Treasury, 2010). Since budgetary stringency continued into 2012 and 2013, public finance has become a top challenge confronting the Westminster parliament, which is seeking new sources of tax income, for example, by proposing a further rise in value-added consumption tax (VAT) from 20% to 25% (The Telegraph, 2012).

A century ago, the Edwardian politicians were similarly faced with a public finance challenge to fund the emerging welfare state programmes, including an embryonic pension scheme (Hattersley, 2004). David Lloyd George, during his Chancellorship of the Exchequer as a member of the governing Liberal party, proposed to tax on tobaccos, luxurious goods, and most important of all,

land, in the 1909 finance bill. These taxation measures were not only intended to balance the government budget, but also to tackle widespread political and economic inequalities faced by the British society. Given its populist flavour, the 1909 budget was often called People’s Budget (Short, 1997). However, the then Conservatives-dominated House of Lords, though reluctantly passing many initiatives included in People’s Budget one year later in 1910, managed to veto the land value tax (LVT) proposal.

The original idea of LVT actually came from the other side of the Atlantic. George (1879), an American political economist born in Philadelphia, Pennsylvania, once wrote:

“The tax upon land values is, therefore, the most just and equal of all taxes. It falls only upon those who receive from society a peculiar and valuable benefit, and upon them in proportion to the benefit they receive. It is the taking by the community, for the use of the community, of that value which is the creation of the community.” (George, 1879, Chapter 33)

George’s central tenet is that the value of land, ultimately, comes from the adjacent infrastructures and amenities invested by the local community. Increments in land value due to public investment therefore ought to be re-captured through LVT. This argument resonates with the ground rent theories by Smith (1863), Ricardo (1891), and even Marx (1867). The tax on land value can also be considered a kind of Pigovian (1920) tax, if one sees the added land value accruing from the positive externalities yielded by community investment (Petrella, 1988).

### *The Contemporaries*

The Pigovian aspect of LVT is perhaps best featured in its contemporary practice, as LVT has been more and more exercised as a way to support the financing of public transport infrastructures (Ryan, 1999; Rybeck, 2004; Smith and Gihring, 2006; Al-Mosaind et al., 1993; Bollinger and Ihlanfeldt, 1997; Bowes and Ihlanfeldt, 2001; Debrezion et al., 2007, 2011; Hess and Almeida, 2007). Underpinning this policy practice is a theoretical conjecture that publicly invested transport facilities adds significant values to the nearby privately owned land plots by improving their spatial accessibilities to the transport network. This kind of public-investment-triggered private land value betterment is a typical instance of positive externalities that could be offset through proper government intervention (Pigou, 1920).

Nonetheless, land value taxation remains unimplemented within the UK, even though some closely associated fiscal interventions do exist in the British town planning practice. For example, section (106) of the 1990 Town and Country Planning Act allows local planning authorities to charge developers, on a case-by-case basis and often by negotiation, a so-called section (106) payment to compensate for the potential negative externalities (e.g., congestion and crowdedness) of new development on the local community (The UK Parliament, 1990). Later, the Barker Review of Land Use Planning (2006) was largely critical of section (106) for its vagueness in concept and inconsistencies in practice. The community Infrastructure levy (CIL) was introduced in the 2008 Planning Act to partially replace section (106) (The UK Parliament, 2008).

Like land value tax, section (106) and CIL are both public financial measures intended for externalities, hence Pigovian by nature. However, LVT differs from section (106) and CIL in being a betterment tax, which tries to capture the positive externalities of community investment in local public infrastructures (Lee et al., 2013). By comparison, the two types of planning charges are employed to compensate for the potential negative externalities of new property developments with respect to the local housing and infrastructure capacities. They are thus essentially the same

thing as what is called “impact fee” in the US (see, e.g., Ihlanfeldt and Shaughnessy, 2004).

Given the subtle and yet important difference between LVT and planning charges, it perhaps makes more sense to look at LVT in reference to the existing UK taxation system.<sup>2</sup> For example, Maxwell and Vigor (2005) suggest substituting LVT for council tax and the stamp duty. They argue that LVT is a levy on land, while both the stamp duty and council tax are estimated by property value and are a property tax. Taxing on property instead of land value involves disincentives for homeowners to maintain and improve their housing conditions – the more they invest in maintenance and renovation, the more property tax liable. This perspective resonates closely with Bourassa's (1990, 1992) earlier empirical studies about a similar topic within the US context, which identified a significant incentive effect of LVT vis-à-vis property taxation.

## Research design

### Research question

Levying land-value tax involves both substantial political as well as technical complexities and constitutes a radical reform to the existing UK public finance regime. Our research focuses more on the empirical and technical aspects of the issue, aiming to explore the ways to assess local public infrastructures' potential contribution to the adjacent land values and to address the according policy implications.

While the word “infrastructure” connotes a variety of facilities (usually of physical presence), this paper concentrates on the relationship between land values and public transport infrastructure in the UK. This is because of the general consensus nowadays regarding the ubiquitous and intimate interactions between transport and land use activities (Geurs and van Wee, 2004). Another reason is that land value taxation, in recent decades, has been increasingly rationalised as a value capture mechanism to finance the development and maintenance of public transport facilities. Last, given the current economic climate, public transport infrastructures in the UK are typically short of funding and thus in need of strengthened fiscal support (Lucas, 2006).

Our specific research question centres on how to assess the spatial relationships between the local public transport infrastructures and the land values of nearby residential properties. A conceptual issue is that housing sub-markets are a salient feature of the British local real estate sector (Orford, 2000). A corresponding methodological framework needs to be in place to capture the latent heterogeneities with regard to the characteristics of different neighbourhood environments, divergent property price levels, and the varying relations between their implicit land values and the nearness to public transport locations.

### A hedonic approach

Given our research question, we employ a hedonic regression approach as the basic modelling method in this study. While Rosen's (1974) seminal theoretical paper recommended a two-stage regression procedure, for this policy-oriented paper, we adopt a reduced-form version of the Rosen original and, as shown in Eq. (1), assume a linear semi-log function form in the first stage of hedonic regression, which allows us to simplify the second stage by directly valuing the bus stop locations based on the corresponding

coefficient estimates (see a similar application, for example, by Heikkila et al. (1989), p. 223):

$$\log(p) = F(H, Y, W, L, \varepsilon) \quad (1)$$

where  $p$  denotes the property's sale price, of which the natural log is a function of  $H$ ,  $Y$ ,  $W$  and  $L$ , plus an error term,  $\varepsilon$ .  $H$  stands for a set of hedonic control variables, each of which corresponds to an attribute of the observed property, in terms of whether it is freehold ( $r$ ), newly built ( $n$ ), detached ( $d$ ), semi-detached ( $s$ ), or terraced ( $t$ ), floor area ( $f$ ), and how far the property is located from the central business district ( $z$ ).  $H$  may be specified as Eq. (2):

$$H = \{r, n, d, s, t, f, z\} \quad (2)$$

$Y$  represents another set of dummy-coded variables capturing the year in which an observed sale transaction took place. This is intended to adjust for temporal effects, such as short term property-price inflation in the local market, with  $X$  denoting the total number of years under observation. If the first year is noted as year 0, we have Eq. (3):

$$Y = \{Y_u | u = 0, 1, 2, \dots, X - 1\} \quad (3)$$

$W$  consists of a series of dummy-coded variables, each indicating a local jurisdiction within which a property is located. These variables capture average local environmental effects related to educational and recreational amenities as well as the overall reputation of the area. Assuming a total of  $M$  jurisdictions within the study area, one of which is denoted as a reference jurisdiction,  $W_0$ , we may define  $W$  as follows:

$$W = \{W_v | v = 0, 1, 2, \dots, M - 1\} \quad (4)$$

It should be noted that the model specification as per Eqs. (4) and (5) may be considered following a ‘discrete-space expansion’ process (Jones and Bullen, 1994, p. 254), whereby the constant term of a regression equation is expanded into the  $(X - 1) + (M - 1)$  dummy variables.

$$L = \{\delta\} \quad (5)$$

$L$  in Eq. (5) represents a set of target variables, which relate directly to the location of land beneath a property. These variables are supposed to measure spatial accessibility and proximity to public transport infrastructure. We assume in this paper that  $L$  consists of only one element  $\delta$ .  $\delta$  in Eq. (5) measures the aggregate number of public transport nodes (e.g., train stations, bus stops, airport terminals) within a buffer or catchment area of an observed property location.<sup>3</sup>

Finally, a couple of standard econometric assumptions are associated with the error term,  $\varepsilon$ . First, we assume independence or zero autocorrelation in the observed values of  $\varepsilon$ . Nevertheless, data collected in the real world are likely to suffer from spatial as well as temporal autocorrelation, depending on how the collection is conducted. Second, we assume a single constant variance in the error term or non-heteroskedasticity. However, this assumption is also subject to post hoc test, given that housing sub-markets are an inherent feature of the UK local real estate industry and therefore the possibility of spatial heterogeneity in implicit prices between sub-markets.

<sup>2</sup> Actually, land value tax (LVT) is also often called single tax, because according to Henry George, the collection of LVT should replace any other taxation schemes, such as those on incomes and consumptions.

<sup>3</sup> It needs to be acknowledged that recent years have seen some highly sophisticated accessibility measures (e.g., Ferrari et al., 2012). While these innovative measures are not the central topic of this paper, they can be very useful for future research.

### Multi-level modelling

Multilevel modelling may be seen as a generalised version of linear regression (Duncan et al., 1998). A multilevel modelling analysis combines both individual and contextual parameters, such as the geographical jurisdiction (e.g., electoral wards) in which a property is located and the years when a property is transacted. Multilevel models are intended to assess the correlation between observations within the same level of analysis and attempt to capture these variations by allowing the regression intercept to vary across, for example, the jurisdictions and the years of sale. This approach is known as a “random intercept” multi-level modelling method (Jones and Bullen, 1994).

$$\beta_{0,v,u} = \beta_0 + \psi_v + \Phi_{v,u} \quad (6)$$

$\beta_0$  in Eq. (6) is the average intercept for all of the observed properties across different jurisdictions and sold in different years.  $\psi_v$  and  $\Phi_{v,u}$  are two independent error components:  $\psi_v$  measures the extent to which the regression intercept for observations within a given jurisdiction,  $W_v$  ( $v=0, 1, 2, \dots, M-1$ ), deviates from the overall averaged constant term,  $\beta_0$ . Likewise,  $\Phi_{v,u}$  measures the difference between  $\beta_0$  and the intercept for observations, not only within  $W_v$ , but also sold in a given year,  $Y_u$  ( $u=0, 1, 2, \dots, X-1$ ).

We deploy this multilevel specification to capture both spatial and temporal land value variations, as per Fig. 1. In Fig. 1(a), the data are grouped geographically in the up most level by electoral ward (our proxy for housing sub-markets), hoped to address potential issues of spatial autocorrelation and heterogeneity. The different years of house sales are then defined as the second level of analysis, in view of dealing with potential temporal autocorrelation. Fig. 1(b) presents an alternative panel structure, where ward remains the first level of analysis and each individual property is now situated at the next stage. However, the year of sale for every property is further defined as a tertiary level. This alternative hierarchy is relevant when a dataset contains many properties that have been sold multiple times during the period of observation.

### Quantile calibration

The method of quantile regression is firstly introduced by Koenker and Bassett (1978). Quantile regression essentially estimates multiple quantiles (e.g. 10%, 50% or 75%) in the dependent variable's conditional distribution. As a result, the approach tends to generate more robust coefficient estimates and provide more comprehensive information about the distribution of the response variable than conventional regression towards the mean (Koenker, 2005).

In the case of this paper, we are concerned with the substantial price differentiation featuring many UK local property markets (Orford, 2000). We hypothesise that properties at the high end of a local real estate market may exhibit systematically different transport-land relations than those at the lower end. In econometric terms, this leads to non-constant conditional variance in  $\log(p)$  (i.e., the natural log of property price), hence a violation of the homoscedasticity assumption. To adjust for the heterogeneous relations between property price and the number of nearby public transport facilities, we apply a bivariate quantile regression method in our post hoc robustness test:

$$\log(p)_q^i = G(\delta, \varepsilon) \quad (7)$$

where  $i$  ( $i=1, 2, \dots, q$ ) stands for the  $i$ th quantile in the conditional distribution of  $\log(p)$ , if the distribution is divided into a total of  $q$  equal intervals.

For demonstration purposes, assume  $K(\log(p))$  as the kernel density function of  $\log(p)$ . One shall see that the quantile estimation

is different from the conventional mean estimation. Specially, to estimate the mean or expected value of  $\log(p)$ , we have

$$E(\log(p)) = \int_{\log(p)_{\min}}^{\log(p)_{\max}} \log(p) \times K(\log(p)) d \log(p) \quad (8)$$

The quantile estimation is however different by solving the below equation in reference to  $\log(p)_q^i$ :

$$\int_{\log(p)_{\min}}^{\log(p)_q^i} K(\log(p)) d \log(p) = \frac{i}{q} \quad (9)$$

A quantile coefficient, given a linear function form, can be worked out through linear programming (Koenker and Hallock, 2001). Acquiring a large number of quantile coefficients in this way enables us to conduct bootstrapping re-sampling and generate an asymptotic kernel density distribution such as  $K(\log(p))$ , allowing an assessment of the asymptotic standard error and confidence interval for every quantile coefficient (Machado and Mata, 2005).

### The case of Cardiff bus

#### The local background

The Welsh Capital city of Cardiff is our study site, because the city exemplifies an array of UK-wide issues with regard to the financing of local public transport. Public services in the UK have experienced widespread funding cuts and austerity measures since 2008. Local public transport is one of the severely affected sectors. For example, in Cardiff, the local council-owned Cardiff bus system witnessed a £0.6 million funding cut by the Welsh Government in 2012, leading to a second increase in bus fare since October 2011 (Wales Online, 2012).

As elsewhere, lack of funding for public transport implicates a number of potential issues in Cardiff. Inflated bus fare, for example, is likely to discourage environment-friendly travel behaviour and push people back into their cars (Newman and Kenworthy, 1999). International experience also shows that restricted public transport tends to make commuting cost particularly unaffordable for the lower income population, exacerbating the “spatial mismatch” between where they live and where they can find jobs (Kain, 1992). Business opportunities can also be affected if they become less accessible due to a shrinking supply of public transport facilities. All of these issues, among many others, alert us to the challenge of financing public transport in a dire economic climate.

Levying land value capture property tax appears to be a promising solution. In the case of Cardiff Bus, a single fare of £1.70 only accounts for the value of bus service to a passenger, while a property owner who lives adjacent to the Cardiff bus network does not necessarily pay the bus fare insofar as not using the service. However, from a George (1879) perspective, the Cardiff Bus network may have promoted the accessibility of its nearby real estate properties, hence contributing to an appreciation of each property's value by a measurable percentage. If this research hypothesis can be substantiated and evidenced, a land value capture taxation scheme becomes justifiable.

#### The data

The dataset used in this study contains observed property prices and bus stop locations mainly within central Cardiff between 2000 and 2009 (see Fig. 2). Our study area covers 12 local electoral wards. The area contains typical Victorian and Edwardian terraced houses, flats in converted buildings and suburban style semi-detached and detached houses, alongside a small number of bungalows and

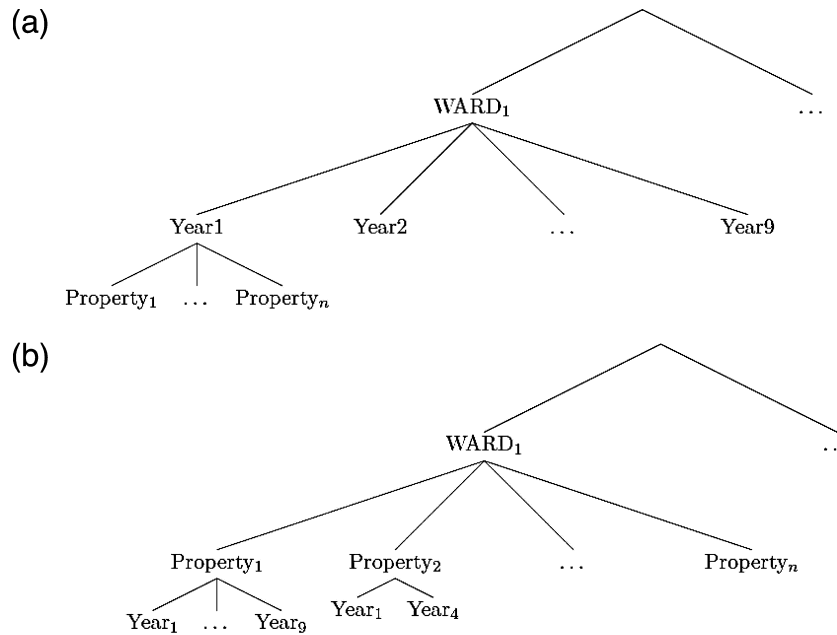


Fig. 1. Cross-sectional (a) vs multilevel panel: (b) structures for property data analysis.

Notes: adapted from Duncan et al. (1998).

Table 1  
Definition of variables and descriptive statistics.

Continuous variables	Definition	Mean	St.dev.
$p$	Property sale price in British pound sterling (£)	143922	87264
$\log(p)$	Natural logarithm of price of the property when sold	11.725	0.5
$\delta_{300m}$	Number of bus-stops within 300 metres (m) off the property	7.4	3.7
$\delta_{400m}$	Number of bus-stops within 400 metres (m) off the property	13.3	5.3
$\delta_{500m}$	Number of bus-stops within 500 metres (m) off the property	20.7	7.4
$\delta_{750m}$	Number of bus-stops within 750 metres (m) off the property	45.2	14.8
$\delta_{1000m}$	Number of bus-stops within 1000 metres (m) off the property	77.7	24.4
$\delta_{1500m}$	Number of bus-stops within 1500 metres (m) off the property	167.7	57.5
$F$	Floor area of a property in square metres (m <sup>2</sup> )	105.2	48.9
$Z$	Distance to the central business district in metres (m)	3225.3	1408.7
Categorical variables	Definition	Proportion	
$r$	1 if property is on freehold tenure, 0 otherwise	89.7%	
$n$	1, if property is newly built when sold, 0 otherwise	3.8%	
Property type			
	Flat as a the reference category	4.1%	
$d$	1, if property is a detached house, 0 otherwise	12.0%	
$s$	1, if property is a semi-detached house, 0 otherwise	25.6%	
$t$	1, if property is a terraced house, 0 otherwise	58.3%	
Year			
$Y_0$	1, if property was sold in 2000, 0 otherwise (reference category)	11.2%	
$Y_1$	1, if property was sold in 2001, 0 otherwise	13.4%	
$Y_2$	1, if property was sold in 2002, 0 otherwise	14.5%	
$Y_3$	1, if property was sold in 2003, 0 otherwise	12.6%	
$Y_4$	1, if property was sold in 2004, 0 otherwise	12.3%	
$Y_5$	1, if property was sold in 2005, 0 otherwise	9.6%	
$Y_6$	1, if property was sold in 2006, 0 otherwise	12.9%	
$Y_7$	1, if property was sold in 2007, 0 otherwise	12.4%	
$Y_8$	1, if property was sold in 2008, 0 otherwise	1.1%	
Ward			
$W_0$	1, if a property is located in Cyncoed (reference category)	11.5%	
$W_1$	1, if property is located in Adamsdown or Butetown, 0 otherwise	12.1%	
$W_2$	1, if property is located in Cathays, 0 otherwise	2.4%	
$W_3$	1, if property is located in Heath, 0 otherwise	1.6%	
$W_4$	1, if property is located in Llanishen, 0 otherwise	1.3%	
$W_5$	1, if property is located in Splott or Rumney, 0 otherwise	23.1%	
$W_6$	1, if property is located in Penylan, 0 otherwise	15.0%	
$W_7$	1, if property is located in Pentwyn, 0 otherwise	17.6%	
$W_8$	1, if property is located in Plasnewydd, 0 otherwise	13.9%	
$W_9$	1, if property is located in Pontprennau, 0 otherwise	1.5%	

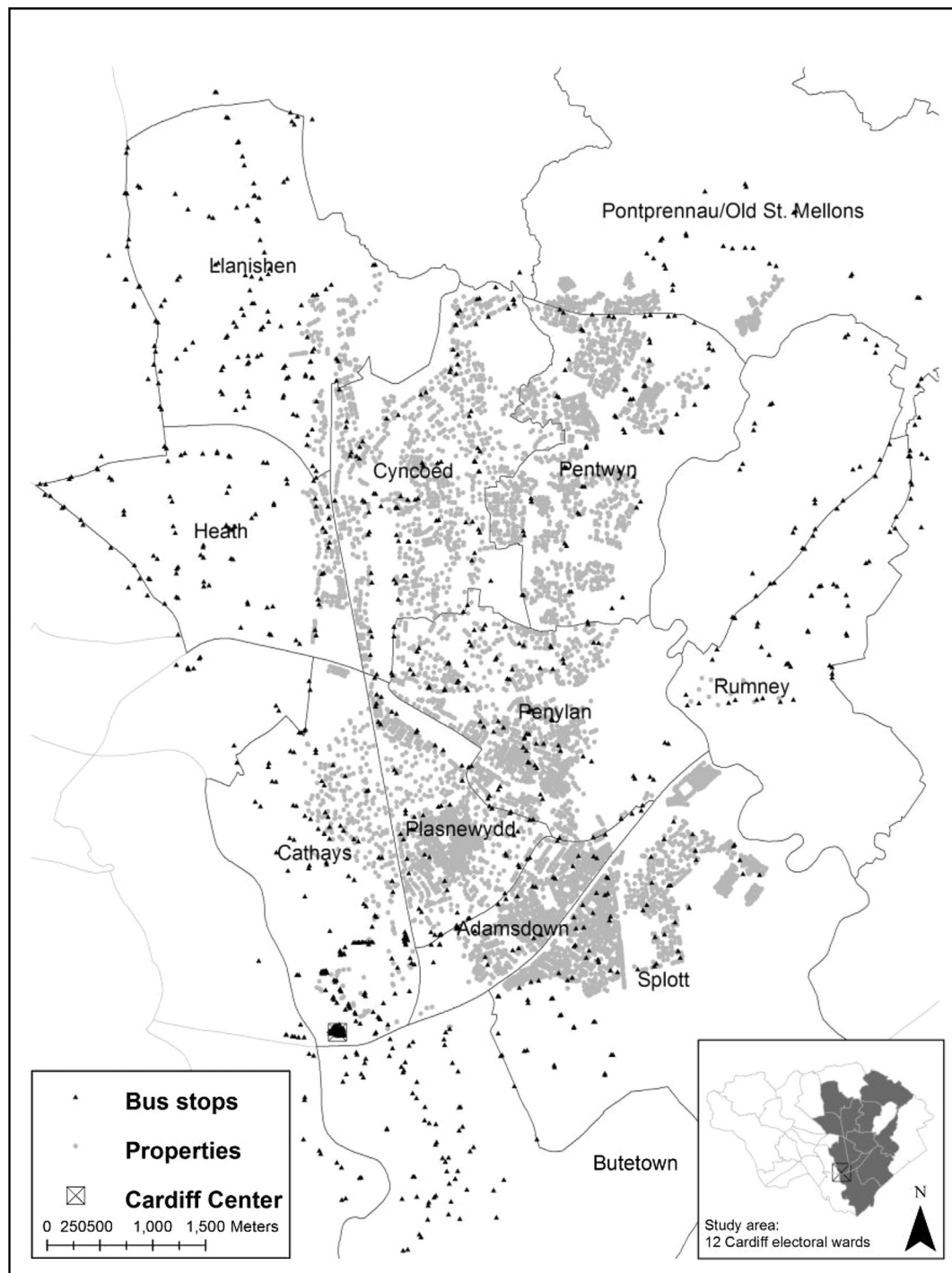


Fig. 2. Properties and bus stops in central Cardiff.

purpose-build flats. Over 9700 residential properties within the area have been sold at least once between 2000 and 2009, providing 12,887 sale records, according to the Land Registry. Apart from the sale records, Land Registry also carries detailed information regarding these properties, including their dwelling types

(detached, semi-detached, terrace or flat), tenures (freehold and leasehold), and whether a property was a new build. Floor area was calculated for every property in the sample using a methodology described in Orford (2010). The bus stop locations are retrieved from the 2007 National Public Transport Access Node

**Table 2**

Number of times a property is sold within the 9-year period of the data.

% in the sample	Number of times a property is sold within the 9-year period of observation						
	1	2	3	4	5	6	7
	75.7	20.0	3.6	0.5	0.1	0.02	0.01

**Table 3**  
Results of ordinary least squares,  $\log(p)$  as dependent variable.

	Model 1 Within 300 m		Model 2 Within 400 m		Model 3 Within 500 m		Model 4 Within 750 m		Model 5 Within 1000 m		Model 6 Within 1500 m	
	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.
Constant	10.506***	0.025	10.479***	0.027	10.438***	0.028	10.417***	0.034	10.343***	0.039	10.269***	0.048
Freehold ( <i>r</i> )	0.120***	0.009	0.121***	0.009	0.123***	0.009	0.126***	0.009	0.127***	0.009	0.125***	0.009
New-built ( <i>n</i> )	0.228***	0.013	0.230***	0.013	0.232***	0.013	0.230***	0.013	0.237***	0.013	0.217***	0.013
Detached ( <i>d</i> )	0.651***	0.016	0.654***	0.016	0.654***	0.016	0.647***	0.016	0.644***	0.016	0.645***	0.016
Semi-detached ( <i>s</i> )	0.468***	0.014	0.471***	0.014	0.469***	0.014	0.465***	0.014	0.464***	0.014	0.465***	0.015
Terraced ( <i>t</i> )	0.360***	0.014	0.361***	0.014	0.359***	0.014	0.356***	0.014	0.354***	0.014	0.357***	0.014
Floor area ( <i>f</i> )	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000
Distance to CBD ( <i>z</i> )	0.035***	0.004	0.038***	0.004	0.042***	0.004	0.046***	0.005	0.055***	0.005	0.066***	0.007
Sale in 2001 ( <i>Y</i> <sub>1</sub> )	0.112***	0.009	0.110***	0.009	0.111***	0.009	0.112***	0.009	0.113***	0.009	0.110***	0.009
Sale in 2002 ( <i>Y</i> <sub>2</sub> )	0.301***	0.009	0.297***	0.009	0.297***	0.009	0.297***	0.009	0.299***	0.009	0.295***	0.009
Sale in 2003 ( <i>Y</i> <sub>3</sub> )	0.526***	0.009	0.522***	0.009	0.524***	0.009	0.525***	0.009	0.522***	0.009	0.520***	0.009
Sale in 2004 ( <i>Y</i> <sub>4</sub> )	0.694***	0.009	0.693***	0.009	0.693***	0.009	0.694***	0.009	0.693***	0.009	0.691***	0.009
Sale in 2005 ( <i>Y</i> <sub>5</sub> )	0.781***	0.010	0.778***	0.010	0.776***	0.009	0.778***	0.009	0.777***	0.009	0.776***	0.010
Sale in 2006 ( <i>Y</i> <sub>6</sub> )	0.791***	0.009	0.789***	0.009	0.789***	0.009	0.791***	0.009	0.791***	0.009	0.789***	0.009
Sale in 2007 ( <i>Y</i> <sub>7</sub> )	0.842***	0.009	0.840***	0.009	0.840***	0.009	0.841***	0.009	0.840***	0.009	0.839***	0.009
Sale in 2008 ( <i>Y</i> <sub>8</sub> )	0.858***	0.023	0.857***	0.023	0.861***	0.022	0.860***	0.022	0.861***	0.022	0.861***	0.022
Adamstown ( <i>W</i> <sub>1</sub> )	-0.512***	0.014	-0.508***	0.014	-0.502***	0.014	-0.499***	0.014	-0.488***	0.014	-0.465***	0.015
Splott ( <i>W</i> <sub>2</sub> )	-0.513***	0.012	-0.507***	0.012	-0.493***	0.012	-0.486***	0.013	-0.464***	0.014	-0.430***	0.017
Cathays ( <i>W</i> <sub>3</sub> )	-0.196***	0.020	-0.194***	0.020	-0.186***	0.020	-0.182***	0.020	-0.164***	0.020	-0.152***	0.021
Heath ( <i>W</i> <sub>4</sub> )	-0.142***	0.019	-0.137***	0.019	-0.139***	0.019	-0.143***	0.019	-0.146***	0.019	-0.144***	0.019
Llanishen ( <i>W</i> <sub>5</sub> )	-0.240***	0.024	-0.250***	0.024	-0.257***	0.024	-0.262***	0.025	-0.269***	0.025	-0.276***	0.025
Penylan ( <i>W</i> <sub>6</sub> )	-0.064***	0.011	-0.064***	0.011	-0.062***	0.011	-0.051***	0.011	-0.039***	0.011	-0.018***	0.013
Pentwyn ( <i>W</i> <sub>7</sub> )	-0.648***	0.010	-0.647***	0.010	-0.643***	0.010	-0.644***	0.010	-0.638***	0.010	-0.638***	0.010
Plasnewydd ( <i>W</i> <sub>8</sub> )	-0.235***	0.014	-0.230***	0.014	-0.225***	0.014	-0.229***	0.014	-0.229***	0.014	-0.218***	0.014
Pontprennau ( <i>W</i> <sub>9</sub> )	-0.500***	0.020	-0.502***	0.020	-0.502***	0.020	-0.506***	0.020	-0.508***	0.020	-0.505***	0.020
Number of bus stops ( $\delta$ )	0.003***	0.001	0.003***	0.001	0.003***	0.000	0.001***	0.000	0.001***	0.000	0.001***	0.000
Sample size	9655		9650		9656		9653		9659		9669	
<i>R</i> <sup>2</sup>	0.850		0.850		0.850		0.851		0.850		0.849	
<i>F</i> -test (df)	2176 (25)		2179 (25)		2185 (25)		2195 (25)		2186 (25)		2167 (25)	
<i>p</i> -Value	0.000		0.000		0.000		0.000		0.000		0.000	

\* $p < 0.1$ ; \*\* $p < 0.05$ .

\*\*\*  $p < 0.001$ .

**Table 4**  
Testing autocorrelation and homoscedasticity in OLS results.

	Model 1 Within 300 m	Model 2 Within 400 m	Model 3 Within 500 m	Model 4 Within 750 m	Model 5 Within 1000 m	Model 6 Within 1500 m
Independence of $\varepsilon$						
Durbin–Watson	1.773	1.777	1.779	1.779	1.779	1.776
p-Value	0.000	0.000	0.000	0.000	0.000	0.000
Spatial autocorrelation						
Moran's $I$	0.150	0.150	0.149	0.149	0.150	0.149
Expected	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
Standard deviation	0.0004	0.0004	−0.0004	0.0004	0.0004	0.0004
p-Value	0.000	0.000	0.000	0.000	0.000	0.000
Homoscedasticity			Breusch and Pagan (1979) test			
$\chi^2$ (df)	0.233 (1)	0.101 (1)	0.533(1)	0.887(1)	1.503(1)	0.612(1)
p-Value	0.6293	0.7512	0.4651	0.3461	0.2202	0.4341

(NaPTAN-v2.2) dataset (Department for Transport, 2007). These are also shown in Fig. 2. The number of bus stops within specified radii of each property (i.e., 300 m, 400 m, 500 m, 750 m, 1000 m, and 1500 m) was calculated using ArcGIS. Table 1 presents a summary of the variables included in the sample of properties in the dataset. Table 2 also shows that this is broadly a cross-sectional rather than panel dataset, as more than 75% of the properties have only been sold once during the 9-year period.

#### Model results<sup>4</sup>

##### OLS results

Table 3 presents the results of six ordinary least square (OLS) regressions based on the conventional hedonic approach prescribed in “A Hedonic Approach” section. The dependent variable in every regression is the natural logarithm of price ( $\log(p)$ ) and all of the six models attempt to capture the effect of Cardiff Bus on land value via  $\delta$ , which measures the number of bus stops within different walkable radii (i.e., 300 m, 400 m, 500 m, 750 m, 1000 m, and 1500 m) around each property contained in the dataset. Following Belsley et al. (1980) a variety of regression diagnostic tests were performed on the OLS models in order to check whether any of the regression assumptions had been violated. These included identifying outliers that may have a disproportionate influence on the models, and removing the corresponding observations if necessary; checking for serious multi-collinearity in the models; testing the normality of the error term; and checking for heteroscedasticity and autocorrelation in the error term. The latter tests are discussed in more detail in a later section.

Model 1, for example, includes the explanatory variable with regard to the number of bus stops within 300 m around each property. The estimated parameter corresponding to this variable shows that the effect of Cardiff Bus on property price or, more accurately, on land value as reflected in property price, is positive and statistically significant at the 1% significance level. In other words, the more bus stops there are around a property, the higher the value of land beneath that property. Similar findings are also discernible from the other regressions estimating the effect of number of bus stops within 400 m, 500, 750 m, 1000 m and 1500 m, respectively.

By back transforming the magnitude of the estimated coefficient with regard to the number of bus stops within 300 m, we can calculate the marginal increase in land value as a result of placing every extra bus stop around a property. In percentage, this

<sup>4</sup> OLS results are estimated in IBM SPSS Statistics 20, while the multi-level analysis is conducted with MLWin v.3.20 (Rasbash et al., 2012). The quantile regression is exercised using an R/SPSS interface based on the original “quantreg” R codes by Koehler (2007).

added land value equals to  $(e^{0.003} - 1) \times 100 \approx 0.3\%$ . Examination of the coefficients of the number of bus-stops within different buffer zones around property in Table 3 suggests that the effect of bus stops within distance is relatively stable and statistically significant. The land value benefit of every additional bus stop within a circular catchment area larger than 500 m by radius is about 0.1% of the corresponding property price. The figure rises to 0.3% if the size of catchment shrinks to 500 m or less by radius. Overall, all models show that the availability of public transport infrastructure can significantly promote land value and thereby raise property price.

The coefficient of  $z$ , the distance to Cardiff's central business district (CBD), is also positive and statistically significant. According to some studies, this finding is counter-intuitive and against the conventional wisdom about urban spatial structure. Per classic urban economic theory (e.g., Anas et al., 1998), property prices should decline alongside increase in the properties' distance to city centre. However, previous studies have also provided several explanations for the positive influence of distance to CBD on property price. For example, the assumption of a declining land value as distance increases from CBD is based on the adoption of a monocentric location choice model (Dubin and Sung, 1987), while Cardiff appears to be a rather polycentric city.

Floor area is also a positive and statistically significant factor in terms of its impact on property price. The effect of floor space is consistent across all six models presented in Table 3. Following a back transformation of the parameter with respect to floor space, we find that every additional square metre in a property increases its value by  $(e^{0.004} - 1) \times 100 \approx 0.4\%$ .

We capture mean spatial variation in property price by using a series of dummy-coded variables representing the wards in which each property is located. The ward named Cyncoed is used as the reference category as it is the area with the highest average property price in the data set. All models show a significant difference in property price from Cyncoed, although the last regression (model 6 in Table 3) indicates no significant difference in property price between Cyncoed and Penylan.

All other coefficients have the expected signs and agree with conventional findings in the hedonic literature (Edmonds, 1984). For example, a property under a freehold tenure is likely to show a higher price compared with a leasehold property. Similarly, a newly built property tends to have more market value than an aged property. Detached properties exhibit the highest prices, followed by semi-detached properties and flats, of which the latter is defined as the reference property type in this analysis. Finally, the dummy variables with regard to price differences due to the calendar year when a property was sold are all significantly different from zero. The year of 2000 is used as the reference year, while the remaining coefficients indicate a constant increase in property price over time, partly due to inflation in pound sterling and partly due to dynamics in the local housing market.



Multilevel results

As mentioned earlier, ordinary least square (OLS) regression may involve potential issues related to spatial and temporal autocorrelations. In terms of spatial autocorrelation, the prices of properties within a same jurisdiction (i.e., electoral wards in our data) are likely to be more similar than those outside. In terms of temporal autocorrelation, properties sold within the same year may show a convergence in sale price vis-à-vis those transacted within a different year. To account for both the geographic as well as temporal autocorrelations, our OLS models would have to be expanded extensively to accommodate  $(M - 1) \times (X - 1)$  interaction factors. In contrast, multilevel modelling analysis appears to be a more efficient alternative to address the issue of autocorrelation (Jones and Bullen, 1994).

Table 4 identifies a problem of autocorrelation underlying all the six OLS models. The Durbin–Watson test suggests an overall significant serial interdependence of the error terms ( $\epsilon$ ) in every OLS model. Because the Durbin–Watson result is more sensitive to temporal autocorrelation, we further exercise a Moran’s  $I$  test (Anselin, 1988), of which the estimates also confirm a presence of a significant albeit weak spatial autocorrelation (Moran’s  $I \approx 0.15$ ). However, the Breusch and Pagan (1979) test for the whole model suggests that heteroscedasticity is not a problem in the error terms and they have constant variance. To address the autocorrelation problem, six multilevel regressions (models 7–12) are further conducted. Since over 75% of the sampled properties are sold only once between 2000 and 2009, we estimate the multilevel models in reference to the cross-sectional hierarchy shown in Fig. 1(a) instead of the panel structure as per Fig. 1(b).

Table 5 illustrates the results of our multilevel modelling analysis. Both the ward-by-ward ( $\sigma_{ward}^2$ ) and year-to-year variance ( $\sigma_{year}^2$ ) are statistically significant, confirming the OLS finding that there are generalisable differences across wards and years in terms of property price. Around 19% of the aggregate variance in property price ( $\sigma_{property}^2$ ) can be attributed to  $\sigma_{ward}^2$ , compared with around 56% to  $\sigma_{year}^2$ . Nevertheless,  $\delta$ , which measures the impact of bus stops on nearby land value, remains stable and is thus unbiased. This essentially confirms the robustness of the OLS estimates, even in face of the identified spatial and temporal autocorrelations.

Quantile results

Table 6 reports the results of our quantile bivariate regressions. As noted above, we conduct this quantile analysis mainly as a post hoc calibration of the OLS estimates, in case price-based heterogeneities lead to a biased coefficient measure of  $\delta$ . We thus use  $\log(p)$  as the dependent variable and  $\delta$  as the only independent variable to gauge the number of bus stops within different walkable distances, from 300 m to 1500 m, around every observed property location.

Generally speaking, Table 6 indicates relatively weak and/or insignificant associations between the number of bus stops and property prices at the 10% and 20% quantiles, where the observed property prices are below £74,000 in the dataset. In contrast, the strongest and most significant correlations can be found for properties at the 80% quantile, priced around £195,000. Those even more expensive properties at the 90% quantile (i.e., £250,000), however, seem to benefit no more from the number of nearby bus stops than those at the 80% quantile, even though they tend to be better off compared with all properties below the 80% quantile, especially when we increase the search radius to more than 750 m.

While confirming the overall robustness of OLS estimates with regard to the mean of  $\delta$ , the results of our quantile analysis do suggest  $\delta$  to be systematically volatile across different price segments.

**Table 5** Results of multi-level modelling,  $\log(p)$  as dependent variable.

	Model 7 Within 300 m		Model 8 Within 400 m		Model 9 Within 500 m		Model 10 Within 750 m		Model 11 Within 1000 m		Model 12 Within 1500 m	
	$\beta_0$	s.e.	$\beta_0$	s.e.	$\beta_0$	s.e.	$\beta_0$	s.e.	$\beta_0$	s.e.	$\beta_0$	s.e.
Constant	10.735***	0.070	10.710***	0.071	10.671***	0.071	10.660***	0.073	10.590***	0.075	10.520***	0.079
Freehold ( $r$ )	0.116***	0.009	0.117***	0.009	0.119***	0.009	0.122***	0.009	0.123***	0.009	0.121***	0.009
New-built ( $n$ )	0.221***	0.013	0.223***	0.013	0.224***	0.013	0.221***	0.013	0.226***	0.013	0.208***	0.013
Detached ( $d$ )	0.659***	0.016	0.662***	0.016	0.663***	0.016	0.655***	0.016	0.653***	0.016	0.654***	0.016
Semi-detached ( $s$ )	0.476***	0.014	0.480***	0.014	0.478***	0.014	0.473***	0.014	0.472***	0.014	0.474***	0.014
Terraced ( $t$ )	0.369***	0.014	0.371***	0.014	0.370***	0.014	0.366***	0.014	0.364***	0.014	0.367***	0.014
Floor area ( $f$ )	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000	0.004***	0.000
Distance to CBD ( $z$ )	0.035***	0.004	0.038***	0.004	0.042***	0.004	0.045***	0.005	0.054***	0.005	0.065***	0.007
Number of bus stops ( $\delta$ )	0.003***	0.001	0.003***	0.001	0.003***	0.001	0.001***	0.000	0.001***	0.000	0.001***	0.000
$\sigma_{ward}^2$	0.034***	0.020	0.033***	0.020	0.033***	0.020	0.033***	0.020	0.033***	0.020	0.033***	0.020
$\sigma_{year}^2$	0.099***	0.016	0.099***	0.016	0.098***	0.016	0.099***	0.016	0.098***	0.016	0.099***	0.016
$\sigma_{property}^2$	0.044***	0.001	0.044***	0.001	0.043***	0.001	0.043***	0.001	0.044***	0.001	0.044***	0.001
Contribution of $\sigma_{ward}^2$ to $\sigma_{property}^2$	0.192		0.188		0.190		0.189		0.189		0.188	
Contribution of $\sigma_{year}^2$ to $\sigma_{property}^2$	0.559		0.563		0.563		0.566		0.560		0.563	
Sample size	9655		9650		9656		9653		9659		9669	

\*  $p < 0.1$ .  
 \*\*  $p < 0.05$ .  
 \*\*\*  $p < 0.001$ .

**Table 6**  
Results of quantile bivariate regressions,  $\log(p)$  as dependent variable and  $\delta$  as independent variable.

Quantile	$\delta_{300m}$		$\delta_{400m}$		$\delta_{500m}$		$\delta_{750m}$		$\delta_{1000m}$		$\delta_{750m}$	
	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.	$\beta$	s.e.
10%	-0.004	0.003	0.001	0.002	0.007***	0.002	0.004***	0.001	0.002***	0.000	0.001***	0.000
20%	0.004	0.003	0.003*	0.002	0.005***	0.001	0.003***	0.000	0.002***	0.000	0.001***	0.000
30%	0.011***	0.002	0.007***	0.002	0.007***	0.001	0.003***	0.001	0.002***	0.000	0.001***	0.000
40%	0.013***	0.002	0.009***	0.001	0.009***	0.001	0.004***	0.001	0.002***	0.000	0.001***	0.000
50%	0.013***	0.001	0.013***	0.001	0.009***	0.001	0.004***	0.000	0.003***	0.000	0.001***	0.000
60%	0.010***	0.002	0.010***	0.002	0.009***	0.001	0.004***	0.000	0.002***	0.000	0.001***	0.000
70%	0.013***	0.002	0.013***	0.002	0.008***	0.001	0.003***	0.000	0.002***	0.000	0.001***	0.000
80%	0.020***	0.002	0.020***	0.002	0.010***	0.001	0.005***	0.001	0.003***	0.000	0.002***	0.000
90%	0.011***	0.002	0.011***	0.002	0.008***	0.001	0.005***	0.001	0.003***	0.000	0.002***	0.000

\*  $p < 0.1$ .  
\*\*  $p < 0.05$ .  
\*\*\*  $p < 0.001$ .

Specifically, spatial proximity to Cardiff Bus stops tends to benefit properties at the high end of the local real estate market. The strongest positive externalities can be observed in properties above the 80% price quantile, with every additional bus stop within a 1500 m buffer zone, for example, contributing to an increase by about 0.22% in property sale price through land value betterment. The corresponding figure for the cheaper properties is halved to around 0.11%.

### Policy implications

The results of our regression analysis based on empirical data from Cardiff have some important policy implications. First and foremost, the outcomes of our ordinary least square regression and multilevel modelling analysis provide convincing evidence to support a classic Georgist hypothesis in the case of Cardiff Bus, that a significant part of the added local property values does come from the land beneath them, or more specifically, from the land plots' geographic adjacency to the bus stop locations. This finding justifies a potential policy intervention in terms of financing Cardiff Bus through a land value tax mechanism, given the substantiated positive externalities yielded by Cardiff Bus.

Second, the results of our quantile calibration entail some even more intriguing practical insights. We find that the positive externalities of Cardiff Bus are distributed unevenly among properties at different price levels in the local real estate market. Generally speaking, according to Table 6, properties at the high end (at the 80% and 90% quantiles) of the market tend to benefit more than those at the low end (at the 10% and 20% quantiles). This implicates a necessity to exercise progressive land value taxation, whereby properties at different price levels need to be taxed at different rates, so that the uneven distribution of positive externalities can be accordingly captured. Our estimation, based on the number of bus stops within a 1500 m radius of every individual property included in our sample data, suggests a tentative land value betterment tax rate of 0.11% per new bus stop for the first tier of properties which are priced below £195,000 and 0.22% for the second tier of properties which are of higher market values.

We notice a somewhat similar progressive taxation mechanism already incorporated in Cardiff's existing council tax system, which divides local residential properties into nine different bands by their estimated values and applies incremental tax rates. There is thus a possibility of introducing an embryonic land value tax element into the current council tax scheme, depending on how we translate the quantile hedonic approach featured in this study into the council taxation system used in practice and also on whether a large enough dataset covering the entire Cardiff Council jurisdiction will become available in the near future.

Third, our overall empirical analysis defies a conventional wisdom that public infrastructure always serves public interest.

Arguably, the case of Cardiff Bus illustrates a free-ride scenario, wherein the most wealthy property owners, intentionally or unintentionally, end up extracting the values of publicly funded transport infrastructures. A similar finding has also been made recently by Banister and Thurstain-Goodwin (2011, pp. 216–221), who suggest land value betterment created by the rail networks to be even more extensive. In this sense, levying land value tax is not only to capture economic externalities, but also to ensure socioeconomic justice and fairness, as per the Edwardian tradition.

### Conclusion and future research

In this paper, we explore the potential viability of levying land value tax within a local UK context. We focus on the empirical and technical aspects by asking how to assess the spatialised relations between the local public transport infrastructures and the land values of nearby residential properties. We answer this question by studying the case of Cardiff Bus. Based on our multilevel and quantile hedonic analysis, we find strong evidence with regard to the positive externalities of Cardiff Bus network towards the market values of nearby residential properties. Given the uneven externality distribution between properties at different price levels, we call for a progressive land value tax scheme.

Because of the political context of our study, we consider action research a key direction of our future research. We would like to take more opportunities to use our research to educate and inform the general public about why land value tax (LVT) is an economically as well as socially desirable idea. Potential oppositions to LVT are less likely from an efficiency perspective, since most classic research has already confirmed that purely taxing on incomes from land would not distort resource allocation (Mills, 1981; Tideman, 1982; Wildasin, 1982). More recent research also shows that it is actually easier than thought to implement neutral or non-distortional land taxation (Arnott, 2005). Even with errors in land valuation, the collection of LVT has been found to result in no more distortions than the conventional property taxation scheme (Chapman et al., 2009). Resistances to LVT are thus more likely about the distributional effects of land taxation, or put simply, regarding how to split the bills that fund public investments. Controversial as this question is, we hope our current study and future research on land value tax will help the voters make an informed decision.

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