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Accessibility and residual land value uplift: Identifying spatial variations in the accessibility impacts of a bus transitway.

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New public transport investment offers the potential to improve accessibility for existing and new users of the public transport network. Transport infrastructure provides land value uplift following improvements in accessibility with uplift benefits being distributed in relation to the proximity of the location of the property to the infrastructure and to both residential and commercial properties. This paper looks at both quantifying the absolute amount of land value uplift and its spatial distribution for accessibility to different destinations for residential properties around a new-build Liverpool Parramatta transitway for buses in a suburban area of South-west Sydney, Australia. Geographically Weighted Regression is used as the methodology to take account of spatial dependency in the estimation process with the results being presented in map form. The results suggest that property prices are mainly determined by the internal features of the property and its neighbourhood effects but accessibility by car and accessibility to employment along the transitway are also contributing in a non-marginal way. The local model shows that accessibility and its value have a geographical component which is statistically significant demonstrating the benefits of undertaking a more disaggregate analysis that allows variation over space to be revealed.
1. Introduction

Developing and updating public transport infrastructure is one of the most expensive, complex and far-reaching investment decisions governments face today. New public transport investment offers the potential to improve accessibility for existing and new users of the public transport network. Accessibility is defined as the ease with which the land use and transport systems allow activities or destinations to be reached by individuals and, in general, improvements in accessibility are translated into enhanced land values in a process normally referred to as land value uplift.

Interest in land value uplift has attracted increasing attention in recent years; particularly as part of a potential (land) value capture policy. Land value ‘capture’, where the land value uplift is ‘captured’ by government to provide funding for public transport investment, is potentially an attractive and innovative mechanism to fund new infrastructure. Quantifying the land value uplift which follows a transport investment implementation is an essential component of evaluating whether a value capture policy is feasible.

Empirically, there is a well established literature that demonstrates that transport infrastructure provides land value uplift following improvements in accessibility with uplift benefits being distributed in relation to the proximity of the location to the infrastructure and to both residential and commercial properties. The impact of new transport infrastructure can vary over time, with expectations increasing land values after the announcement of new transport infrastructure and before its completion, giving rise to different short-term and long-term impacts, as shown in Du and Mulley (2007a).

This paper looks at the spatial distribution of land value uplift for accessibility to different destinations, for residential properties around a new-build transitway for buses in a suburban area of South-west Sydney, Australia. It thus contributes to the existing literature in two ways: by its focus on bus-based infrastructure and by the consideration of the spatial distributional effects.

2. Literature

This section outlines the theoretical foundation for the empirical work presented in this paper. It first addresses the foundations of land rent theory to identify the basis for land value uplift before turning to the empirical evidence on the relationship between public transport provision and land use. The final section reviews the existing evidence of the effect of public transport on land value.

2.1 Foundations of land value uplift

The land rent theory, developed by Alonso (1964) and Muth (1969), is the theoretical framework for the relationship between accessibility and land values. These theories purport that land rent (and therefore the underlying land values) reflects accessibility gradients with higher values of rent reflecting higher accessibility to goods and services.

In an urban context this suggests that locations with better accessibility have a higher rental value where rental value is the annualised capital value. New transport infrastructure, where it increases accessibility, will therefore increase rental value and hence land values. This will be the case for all forms of transport improvement, whether it is road improvement or a public transport investment.

Whilst there is significant debate in the transport planning literature about the definition of “accessibility”, this paper adopts a definition where accessibility is the ease with which the land use and transport systems allow activities or destinations to be reached by individuals (Morris et al. 1979, Handy and Niemeier 1997, Zhu and Liu 2004, Horner and Mefford 2005). Public transport investment changes lead to changes in accessibility for residents in properties within the catchment area of the new or changed infrastructure because some activities and destinations are nearer or can be reached more quickly or at lower cost or with a reduced generalised cost. Thus changes in accessibility can be
seen to drive changes in land value, creating value uplift in the presence of enhanced transport infrastructure.

2.2 Public transport provision and land use

Knight and Trygg (1977) drew together data from a number of cities in North America to examine the links between public transport provision and land use. This early study was qualitative and drew tentative conclusions on the ability of public transport to promote new development and growth. In particular Knight and Trygg questioned the ability of public transport provision to drive substantial land use change, especially if other factors principally relating to the co-ordination of transport and land use planning were not present.

The paper by Knight and Trigg (1977) laid the foundation upon which subsequent studies have aimed to give more quantitative evidence. In the developed world Knight and Trigg (1977) was followed by Huang (1966) which updated the earlier paper in terms of adding new studies but coming to very similar conclusions. San Francisco, California was the setting for the investigation of the land use impact of the BART transport system by Cervero and Landis (1997). The BART system was implemented as a significant regional public transport system but even after 20 years, BART was not associated with large scale land use changes overall although it was identified as an important contributor in localised developments. Gospodini (2005) reviewed twelve cities across Europe which had implemented varying sized transport infrastructure projects and concluded that transport infrastructure projects can be the catalyst for land use change within areas but that the scale of the effect depends on a number of factors outside the control of the transport infrastructure itself. Large public transport projects serving large geographical areas have a bigger potential, the location of the transport investment had more impact if there was space for further development and a market pressure for particular types of development and the institutional framework and politics could encourage by providing a positive environment for change.

The evidence from East Asia, cited by Salon and Shewmake (2011) suggests that public transport is much more likely to act as a development ‘magnet’ than appears to be the case in North America and Europe. This is attributed particularly to the much lower levels of car ownership in East Asia. This means that public transport is more the means of achieving accessibility in contrast to North America (in particular) and Europe (to a lesser extent) where public transport users tend to be ‘captive’ users. Moreover, cities in East Asia are growing rapidly and this provides the environment for public transport and land use to reinforce development.

Whilst there is no directly relevant Australian literature, an early paper by Newman and Kenworthy (1996) identify key Australian characteristics. Australian cities are ‘second only to US cities in their degree of automobile dependence” (Newman and Kenworthy 1996, p.20) and, like the US, the major Australian cities have very low density. Whilst there is more recent evidence suggesting a reverse of an earlier decline of the urban city centres in Australia, the statistics identify public transport use as being dominated by captive riders or users who may have access to a car but use public transport because it is difficult to park at the destination (53% in Sydney in 2009/10, Table 4.3.4, (BTS 2011)).

Public transport investment in Australia has led to some success stories, notably the strong and continued growth in patronage found in Brisbane, Queensland following the implementation of bus rapid transit (8% for 2008/9 (translink.com.au)).

In summary, public transport can deliver the impetus for land use change but the scale of change depends on many factors. Not least, as all the studies identify, there are problems of separating out of public transport induced effects from other effects happening contemporaneously.

2.3 Evidence on public transport investment and value uplift

RICS (2002) and Smith and Gihring (2006, 2009) together provided major reviews of over 100 international studies on the impact of public transport on property values: these reviews identified that the impacts of public transport has focused almost exclusively on the impact of rail projects (heavy rail, metro and light rail). Once built, rail based infrastructure is regarded as fixed and so any
improvements in accessibility are perceived as permanent. Bus Rapid Transit (BRT) is a high capacity urban public transport system, typically with its own right of way (as for rail based modes) which is gaining in popularity in cities around the world because of its better cost effectiveness (vis-a-vis light rail), quicker implementation and its ability to provide for large numbers of passengers with high passenger attractiveness. However, the impact of BRT infrastructure to land value uplift is an area that has been relatively neglected in the literature.

BRT has been hugely successful in developing countries. Rodriguez and Targa (2004) and Munoz-Raskin (2010) have studied the impact of BRT in Bogota, Columbia and some evidence of land value uplift was found. With an increase in BRT penetration, more studies have very recently become available (Deng and Nelson 2010 for Beijing, China, Cervero and Kang 2011 and Jun 2012 for Seoul, Korea). In developed countries, Cervero and Duncan (2002a, 2002b) investigated the effect of BRT in Los Angeles, US, but found no evidence of value uplift, Perk and Catala (2009) reported a study in Pittsburgh where uplift values in excess of the uplift value attributed to new light rail was found, although the authors suggested other factors could have caused this and Dubé et al. 2011 in Quebec, Canada, found only properties located far enough away to avoid noise but close enough to use the BRT experienced value uplift.

The literature on value uplift demonstrates highly variable average levels of uplift or premiums. This is partly due to studies being in different locations but also due to different methodological and data constraints of the studies. The more sophisticated studies have relied on hedonic pricing models, although this is an incomplete method as spatial variation and potential spatial correlation between variables is ignored (So et al. 1997) and the methodology assumes the impact of accessibility on property values is fixed over space. Only one study, using Geographically Weighted Regression (GWR) (Fotheringham et al. 2002), took account of spatial interactions and allowed the impact of accessibility and other variables to vary over space: this was a light rail study in the North-east of England, UK (Du and Mulley 2006, 2007b). Du and Mulley (2006, 2007b, 2011) showed land value premiums varied with statistical significance over geographical space in the study area, thus providing an explanation for the highly variable average levels of uplift displayed in the literature.

3. Methods to evaluate impacts of public transport on land value

Methods which have been used to evaluate impacts exploit a number of different features to varying degrees.

For residential impacts, simple comparison methods examine the relationship between land value or property price and transport accessibility by isolating transport accessibility from other factors through comparisons of land value/property price. This is undertaken by first identifying ‘treatment’ and ‘control’ areas affected and not affected by the public transport infrastructure improvement and then compare house prices from before and after implementation for the catchment areas of the new public transport (‘treated’ area) and the control areas. Studies using this approach for North American and European cities include TRRL 1984; Cervero and Landis 1993; TRRL 1993; Pasha 1995 and Du and Mulley 2007a. But this method seems unable to identify the more complicated, multi-dimensional features which underpin property values.

Hedonic pricing methods examine the impact of transport infrastructure on land values by standardising for a number of attributes in a multiple regression model with the dependent variable of land value/property price. Hedonic models have been the most common approach to analyse property prices using a multiple regression methodology to explain house prices as a function of a number of house specific explanatory variables. It has been widely considered to be the best method available to identify the effects on house prices associated with factors such as proximity to transportation facilities (Cervero and Duncan 2001). However, literature (Landis et al. 1994; Cervero and Duncan 2002a, 2002b) points to the variability of transport accessibility and land value over space: in hedonic
modelling this has been met either by applying hedonic price models to submarkets or to different types of properties as in Adair et al. (2000). However, these approaches require the land area to be subdivided using some arbitrary ‘rule’ to give boundaries for the separate hedonic models.

More sophisticated changes to hedonic modelling have included taking account of spatial dependence in the data by the modelling process. Spatial effects may occur in two different forms: one is spatial dependency, or its weaker expression spatial autocorrelation (they are not identical though they are often used interchangeably in the literature), and the other form is spatial heterogeneity, or spatial non-stationarity (Anselin 1999). Spatial models which recognise directly this variability have become more accessible in recent times through improvements in computing power and available software. These spatial models divide into two main categories. Spatial lag and spatial error models which attempt to correct for spatial dependence in the error term as part of the estimation process and produce results which are interpreted in much the same way as hedonic models. An alternative, Geographically Weighted Regression (GWR), developed by Fotheringham et al. (2002), again takes account of the spatial dependency in the estimation process but the output can be presented in map form thus allowing the spatial variation of the data to be revealed. GWR was first used in the transport sector by Du and Mulley (2006, and 2007b) to compare hedonic pricing and local modelling approaches for land value uplift with more recent applications being used to estimate local models of trip end transport demand for rail (Blainey 2009). This paper adopts GWR as the methodology for identifying land value uplift.

GWR provides a number of advantages over the hedonic model, including those models which try to account for spatial effects in the error structure of the model. One of the major advantages of GWR is that it tackles both spatial non-stationarity by accounting for coordinates in parameter estimates, but also spatial dependency by taking into account geographical location in the intercepts. In the context of modelling land value, part of the spatial variation will be due to differences in preferences of the different households which are distributed over space. Other spatial variation will arise from the different effects of administrative or political boundaries on, for example, land use mix.

The extension provided by GWR is below demonstrated in a traditional cross-sectional regression model. In this study, where the dependent variable Y is land value, the cross section model can be extended from

\[ Y = \beta_0 + \sum \beta_i X_i + \epsilon, \]

(1)

to a model in which local variations in the parameter values can be revealed by taking account of coordinates of the variable. If the dependent variable has coordinates \((u_i,v_i)\), the model expressed in (1) above can be rewritten as:

\[ Y_i(u_i,v_i) = \beta_{0i} + \sum \beta_{ij} (u_i,v_i) X_i + \epsilon_i \]

(2)

Estimation is a trade-off between efficiency and bias in the estimators. The Akaike Information Criterion (AIC) is one of the measures used for evaluating the explanation given by GWR models as, in addition to measuring goodness of fit, it takes the complexity of the model into account. The GWR spatial analysis has now been incorporated in ArcGIS software although this has less diagnostic features than the specialised software used for this paper. One of the limitations in the use of GWR is that it is a data hungry analysis tool. The local model effectively produces a local regression for each data point and this uses substantial degrees of freedom.

The next section provides information on the area in which the empirical study for this paper is set. This is followed by a more detailed exposition of the model and data employed.
4. The Liverpool Parramatta transitway in SW Sydney, Australia

The Liverpool Parramatta transitway (LPT) is a bus rapid transit (BRT) system which connects the major centres of Liverpool and Parramatta in the SW of Sydney, Australia. The termini are in Liverpool Local Government Area (LGA) and Parramatta LGA respectively. The transitway route traverses the two further LGAs of Fairfield and Holyroyd. The intention of the infrastructure was to provide North-South public transport services connecting Liverpool in the south, Parramatta in the north and suburbs along the route to major employment, education and recreation centres (NSW Audit Office 2005). The 31 km route with 33 stations includes 20 km of new dedicated bus-only infrastructure and 10 km of on-road bus priority. Transitway stops were designed to emulate rail-based public transport rather than simple bus stops. Figure 1 shows the route of the LPT.

The building of the LPT was announced in mid 1998 and opened in February 2003 at a final cost of over $350 million. The aim of the LPT was to markedly change accessibility in south west Sydney in providing a new north-south public transport link where existing local bus services provided local east-west links, and by using dedicated infrastructure to provide a high quality public transport experience with faster, more reliable services. In the first year of operation, the actual patronage was just under 1 million passengers and this rose to nearly 2m in February 2006. Patronage on the transitway continues to grow with the most recent figures for 2009/2010 showing patronage at 2.6m (NSW STA 2010).
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Figure 1: The Liverpool Parramatta transitway

Source: NSW Audit Office 2005, p.11
Bus services in NSW were re-organised in 2005 with the creation of 15 new Metropolitan Contract Regions replacing the former 87 contract areas. The intention was for a progressive review of bus services in each Contract Region to create a network of strategic bus corridors as the backbone of an integrated bus network for the Sydney Metropolitan Area. For Region 3, in which the LPT is largely situated, the new bus contract review did not occur until 2007 with the east-west bus network in place at the opening of the LPT remaining virtually unchanged until this date.

The LGAs through which the LPT operates are quite diverse. Fairfield is recognised as one of the most diverse LGAs in Australia, attracts new migrants which are reflected by over half of its population being born overseas. The Australian Bureau of Statistics’ SEIFA (Socio-Economic Indexes for Areas), using 2006 census data, covers all areas in Australia and is designed to have an average of 1000. In all the LGAs of the study area, these are identified as relatively disadvantaged with Liverpool at 966, Fairfield at 876, Holroyd at 972 and Parramatta at 987.

The LPT offers the opportunity to examine the land value uplift consequent on bus infrastructure investment. Importantly, the aim of the transitway was to improve accessibility rather than increase capacity and the accessibility changes are relatively self-contained. The transitway was designed to be a trunk route within an integrated network, and not simply to give the wider spatial coverage typical of buses. It has significant dedicated infrastructure and a service pattern similar to a rail link. All these factors are important methodologically as it limits significant confounding changes which could interfere with the identification of land value uplift.

5. Modelling of land value impacts of the Liverpool Parramatta transitway

5.1 Modelling approach

House prices are determined not only by the features or quality of the house itself but also external factors such as the neighbourhood and the accessibility of the house location. The modelling approach of this paper is to relate the dependent variable of house price, $P$, to a group of variables as shown in equation 3.

$$P_i = f(C, N, T) \quad (3)$$

Where $C$ is a vector of characteristics relating to the property itself such as its size, $N$ is a vector of neighbourhood effects such as underlying socio-demographic features and $T$ is a vector of transport accessibility measures measured in time.

The GWR methodology first estimates a global regression model which is equivalent to a hedonic price model and then a local model, in which the co-ordinates of the dependent variable are used to account for local variations in the parameter values. In effect, the local model provides a regression for each point in the spatial area under consideration. A unique advantage of this approach is that each observation is treated relative to its location in space rather than lying within an artificially bounded geographical area (for example within a particular political boundary such as the LGA) as is required by other methodologies used in spatial analysis.

The estimation of equation (2) for the local model is by weighted least squares. The estimation weights are chosen so that the predicted values of $y$ are more influenced by observations close to the location $(u,v)$ than those further away. The weighting process uses spatial kernels which capture the data points to be regressed by moving the regression point across the spatial area under consideration. The results are sensitive to the choice of bandwidth (the distance captured by the spatial kernel) and this paper uses the option provided by the GWR to use adaptive spatial kernels which narrows the bandwidth where data are dense but allows it to spread where data are spread. As identified above, the Akaike Information Criterion (AIC) (Akaike 1973) is used as the measure for evaluating the explanation given by GWR models using the rule of thumb that the local model is an improvement over the global model if its AIC is more than 3 units smaller (Fotheringham et al 2002).
5.2 Data acquisition

In practical terms, collecting sufficient disaggregate data is the most critical aspect of applying GWR. The data used to estimate the model of equation 3 are discussed in turn below.

5.2.2 Property data

Equation 3 shows the dependent variable to be the house price. The house price is however an improved land value and not the underlying land value affected by accessibility improvements. The modelling approach is to use residential property prices but to standardise for the internal and external features of the property (vector C in equation 3) to identify the underlying land value.

Transaction property price data were sourced from RPdata who collate information from a number of different sources, including the Valuer General and Land Title offices. The requirement was to provide information on the transaction price, the contract date of the sale, property type (house, townhouse or unit), area size, the number of bedrooms, bathrooms, number of parking spaces and the latitude and longitude for properties sold in 2006 in the LGAs of Liverpool, Holroyd, Fairfield and Parramatta. Sales between related parties (so called ‘love and affection’) were excluded from the dataset. 2006 was three years after the opening of the transitway and thus the value uplift identified in this paper relate to the longer term impacts of the investment. In all, 4184 properties for the four LGAs of Liverpool, Fairfield, Holroyd and Parramatta were available for analysis.

The empirical analysis concentrates on the accessibility of properties influenced by the infrastructure investment of the LPT. The LGAs of Liverpool and Parramatta in particular, and Holroyd and Fairfield to a lesser extent, cover a greater geographical area than this. In order to balance capturing all properties that could be affected by the transitway but excluding properties where confounding accessibility characteristics could be present, properties beyond 1500m of the transitway were deleted. This was guided by empirical evidence that suggests individuals are prepared to walk further to a rail-based public transport station as compared to a bus-based public transport stop with 800m and 400m planning ‘rules of thumb’ being applied respectively in defining catchment areas for rail and bus respectively. Although the transitway ‘stations’ of LPT were designed to emulate rail public transport stations, it was decided that taking a 1500m spatial area around the transitway would be appropriate. This excluded a further 2585 properties (61.8%) and provided a total of 1598 properties for analysis.

The raw data identified houses and town houses separately. However, this classification was thought not to be entirely correct since only 60 properties (3.8%) were identified as not being units (including townhouses (60), semi-detached (2), villas (29) and duplex (15)) which were added to the property type ‘house’ in the analysis.

In other studies, an important single measure of ‘size’ of a property has been its square area. In the Australian case, the area recorded with a property sale is the area of the plot. This has the unfortunate consequence of associating the area of the plot (the external area of the site) of a unit (apartment or flat) with the transaction price of that unit. Consideration was given to restricting the analysis to residential houses only but this was dismissed on the grounds that units form an important part of the housing stock and building units is a serious focus of the NSW government in its planning focus to increase density. Thus in this study, the number of bedrooms, bathrooms and parking spaces were used to standardise for the size of the property, alongside the house or unit distinction.

The contract date on which the property was sold was distributed throughout 2006. Although this paper adopts a cross-sectional approach and there was not much price movement in this period, the transaction price could be confounded by seasonal and other effects. Accordingly the transaction price was adjusted by a house price index formulated by the median sale price for each LGA over the period, sourced from the NSW Family and Community Services.
5.2.2 Neighbourhood environment data

Neighbourhood environment data, including socio-economic data is used in equation 3 (as the vector N) to explain the external characteristics influencing house prices. The purpose of standardising for these external effects is to allow the effect of transport accessibility to be observed.

A number of potential variables were identified from the Australian Bureau of Statistics (ABS) 2006 census data, available at the Collection District (CD) spatial level. A CD is the smallest spatial level for which census data is available and represents, on average, 225 properties. Each property in the dataset described above was linked with its corresponding CD for the purposes of assigning census information.

The income of the area was examined by a number of individual income, individual education achievement levels, unemployment levels and individual occupation variables. Many of these were highly correlated. In particular education achievement levels were highly correlated with income and occupation variables, as expected.

As identified above, the LGAs of Liverpool and Fairfield in particular attract new migrants to Australia. The ethnicity of the area was investigated by a number of variables, collected in the census, related to ancestry, the length of time in Australia and the degree to which the primary language at home is not English. The length of time in Australia and the degree to which the primary language at home was not English were highly correlated and the different ancestry backgrounds were inconsistently correlated with the educational attainment variables.

A number of different formulations for both income and ethnicity variables were constructed from the ABS data for use in the empirical analysis.

5.2.3 Accessibility variables

The accessibility variables were calculated in a number of ways for the empirical analysis. The focus was on measures using bus services and on accessibility measures for car, as a competing mode.

Public transport access for shopping and employment focussed on those centres linked by the new investment in the transitway. As can be seen from Figure 1, journeys between Liverpool and Parramatta are more likely to be undertaken by rail (for both reasons of directness and travel time). Accessibility measures were calculated as the time to the nearest employment centre or nearest shopping centre (as shown on Figure 2 below) from each house location. A more specific transitway accessibility measure looked at the smaller of the travel times to Liverpool or Parramatta using the shortest road distance to the transitway at a walking speed of 80m/min (Du and Mulley, 2007b, citing O’Sullivan and Morrall, 1995), waiting times of half the peak frequency and peak bus travel times. This measure reflects that the catchment areas for Liverpool and Parramatta respectively are clustered around the respective major centre, as shown by the background profile information for the network review for Metropolitan Contract Area 3 in 2007 (NSW 2007, p.10).

Ryan (1999), as cited by Armstrong and Rodriguez (2006), argued that the accessibility benefits of a transport mode should be considered relative to other modal options. To control for this the driving time to the nearest motorway access, using network speeds appropriate to the road link, was calculated for each property in a similar way to that undertaken by Armstrong and Rodriguez (2006). In addition, travel times by car to Liverpool and Parramatta were calculated but these, not surprisingly, were highly correlated with travel time by bus to Liverpool and Parramatta.

Finally, whilst closeness to public transport stops is known to increase public transport use, being too close may expose properties to the negative externalities of noise and environmental pollution. A series of buffers at different distances from the route of the transitway were employed to investigate this impact.

As with data for external factors discussed in Section 5.2.2, a number of different accessibility variables were calculated for public transport access and access by car for use in the empirical analysis.
6. Results

As the GWR local model is an extension of the global or hedonic model estimation, the challenge is to find the ‘best’ model for both global and local estimation. As it is not necessarily the case that the best global model leads to the best local model, the approach in this paper is to achieve the best global model, consistent with sensible local model results.

Correlation issues identified in Section 5 limits the combinations of variables that can be used simultaneously to standardise house prices in the global model so the impact of transport accessibility can be observed. Multicollinearity is a potential problem in all regression-based analysis and has the effect of inflating the standard errors of the estimated parameters and reducing their observed significance, whilst $R^2$ and the adjusted $R^2$ remain unaffected. The approach in this paper is to check correlations between independent variables on the basis of high correlations among the independent variables will make multicollinearity likely whilst the converse, low correlations, may not suggest the absence of multicollinearity. This is because complex interactions may exist between the independent variables which are not revealed in a pairwise correlation investigation. A further check in the analysis centred on the stability of the parameter estimates and their standard errors since multicollinearity is known to have a destabilising effect.

As Wheeler and Tiefelsdorf (2005) show, local models may have more serious multicollinearity issues than their associated global models. Multicollinearity in the local models has the same impact as for the global model where inflated standard errors lead to a reduction in observed significance. Wheeler and Tiefelsdorf (2005) identify this as a real issue if GWR is used as a data exploratory tool. They suggest scatterplots of pairs of local parameter estimates should be undertaken to investigate local multicollinearity and that the local parameters should be interpreted in the context of the global parameter results. However, Wheeler and Tiefelsdorf do not suggest the interpretation of the local parameters against a backdrop of the local parameter significance, calculated as t-values from the GWR output. By interpreting local parameter estimates in this manner, as is done in this paper, the significance of the local parameter estimates will be under-claimed in the interpretation if multicollinearity is present.

6.1 The global regression model

A number of different functional forms were investigated in the estimation procedure. The final form estimated was a semi-log form, chosen for the well behaved nature of the residuals and is shown by equation 4

\[
\text{Ln } P_i = \alpha_0 + \alpha_1 \text{BEDROOMS}_i + \alpha_2 \text{BATHROOMS}_i + \alpha_3 \text{PARKING}_i + \alpha_4 \text{UNITBED}_i \\
+ \alpha_5 \text{ENGLISH} + \alpha_6 \text{UNEMP} + \alpha_7 \text{INCOME}_i \\
+ \alpha_8 \text{ACCESS\_MOTORWAY}_i + \alpha_9 \text{BUS\_MAJORCENTRE}_i + \alpha_{10} \text{BUS\_SHOP}_i \\
+ \alpha_{11} \text{BUS\_EMP}_i + \alpha_{12} \text{100mBUFFER} 
\]

where

Property characteristics:

BEDROOMS is the number of bedrooms, BATHROOMS is the number of bathrooms and PARKING is the number of parking spaces associated with each property. HOUSE and UNIT are a set of dummy variables depicting the type of property and are incorporated in the model as an interaction term with BEDROOMS to give UNITBED to capture the conditional effects of the number of bedrooms and type of property.

Neighbourhood effects: ENGLISH is the % of individuals where English is the primary language spoken at home and is an inverse measure of the ethnicity of the neighbourhood. UNEMP is the percent of unemployed persons looking for work and INCOME is the percent of individuals with
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gross income of more than 1600$ per week (which is slightly below the median income for Sydney metropolitan area (2006 census)).

Accessibility measures: ACCESS_MOTORWAY is the time to the closest motorway access, BUS_MAJORCENTRE is the smaller of the bus travel times to Liverpool or Parramatta (including walk and wait times), BUS_SHOP is the shortest travel time by bus to a local shopping centre and BUS_EMP is the shortest travel time by bus to one of the two employment centres served by the transitway. 100mBUFFER takes the value 1 if the property is within 100m (straight line distance) of the transitway route.

Table 1 provides a description of the variables and summary statistics of the variables providing the global model and local model presented in this paper. Table 2 provides the results for the global regression

Table 1: Variables and their descriptive statistics (n=1598)

<table>
<thead>
<tr>
<th>Units</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE $</td>
<td>227425.470</td>
<td>71212.063</td>
</tr>
<tr>
<td>Ln Price $</td>
<td>12.286</td>
<td>0.317</td>
</tr>
<tr>
<td>BEDROOMS $</td>
<td>2.864</td>
<td>0.850</td>
</tr>
<tr>
<td>BATHROOMS $</td>
<td>1.320</td>
<td>0.556</td>
</tr>
<tr>
<td>PARKING $</td>
<td>1.200</td>
<td>0.801</td>
</tr>
<tr>
<td>ENGLISH % of Individuals in the CD</td>
<td>38.472</td>
<td>14.983</td>
</tr>
<tr>
<td>UNEMP % of Individuals in the CD</td>
<td>3.816</td>
<td>1.463</td>
</tr>
<tr>
<td>INCOME % of Individuals in the CD</td>
<td>2.246</td>
<td>1.358</td>
</tr>
<tr>
<td>ACCESS_MOTORWAY minutes</td>
<td>3.024</td>
<td>1.958</td>
</tr>
<tr>
<td>BUS_MAJORCENTRE minutes</td>
<td>34.615</td>
<td>12.526</td>
</tr>
<tr>
<td>BUS_SHOP minutes</td>
<td>12.271</td>
<td>7.162</td>
</tr>
<tr>
<td>BUS_EMP minutes</td>
<td>33.138</td>
<td>11.369</td>
</tr>
</tbody>
</table>

Table 2: Results of the global model (n=1598)

<table>
<thead>
<tr>
<th></th>
<th>Estimate of $\beta$</th>
<th>Standardized Coefficients ($\beta$)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>12.316</td>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td>BEDROOMS</td>
<td>0.127</td>
<td>0.341</td>
<td>0.000</td>
</tr>
<tr>
<td>BATHROOMS</td>
<td>0.102</td>
<td>0.180</td>
<td>0.000</td>
</tr>
<tr>
<td>PARKING</td>
<td>0.030</td>
<td>0.076</td>
<td>0.000</td>
</tr>
<tr>
<td>UNITBED</td>
<td>-0.095</td>
<td>-0.299</td>
<td>0.000</td>
</tr>
<tr>
<td>ENGLISH</td>
<td>-0.002</td>
<td>-0.089</td>
<td>0.000</td>
</tr>
<tr>
<td>UNEMP</td>
<td>-0.043</td>
<td>-0.198</td>
<td>0.000</td>
</tr>
<tr>
<td>INCOME</td>
<td>0.067</td>
<td>0.286</td>
<td>0.000</td>
</tr>
<tr>
<td>ACCESS_MOTORWAY</td>
<td>-0.042</td>
<td>-0.262</td>
<td>0.000</td>
</tr>
<tr>
<td>BUS_MAJORCENTRE</td>
<td>0.001</td>
<td>0.040</td>
<td>0.112</td>
</tr>
<tr>
<td>BUS_SHOP</td>
<td>-0.007</td>
<td>-0.160</td>
<td>0.000</td>
</tr>
<tr>
<td>BUS_EMP</td>
<td>-0.007</td>
<td>-0.250</td>
<td>0.000</td>
</tr>
<tr>
<td>100mBUFFER</td>
<td>-0.092</td>
<td>-0.064</td>
<td>0.000</td>
</tr>
</tbody>
</table>
The diagnostic information suggests that 64% of the variation in the dependent variable is explained by this global model (adjusted $R^2$) which is a good fit given the cross-section nature of the data. As this is a semi-log functional form, the interpretation of the estimated coefficients relates to their proportional (or when multiplied by 100, the percentage) effect on Price. For the internal factors of the property, it can be seen that there is significant interaction shown by the variable UNITBED between the size of the property, measured by the number of bedrooms, and the property type (house or unit) as well as a significant estimated coefficient for the number of bedrooms. The interpretation of this interaction term is that, for the property type ‘unit’, there is a differential impact of the number of bedrooms on the price of units, as compared to houses. To understand the impact of an additional bedroom in a unit, the estimated parameter for BEDROOMS needs to be taken into account. Thus the global regression suggests, ceteris paribus, an additional bedroom in a unit will lead to 3.2% ($0.127 – 0.095 = 0.032$) increase in price.

Unemployment, income and the degree of non-English spoken in the home (since migrants typically have lower paid employments than residents of Australian ancestry) are indicators of the relative influence and composition of the neighbourhood in which the property is located. The percentage of unemployed in the area (UNEMP) might be expected to vary inversely with property value. Having a higher percentage of residents with high incomes (INCOME) and the percentage of individuals where English is the primary language at home (ENGLISH) might be expected to lift property value. These variables are all significant in the global regression with UNEMP and INCOME having the expected sign and ENGLISH having the opposite to expected sign. So ceteris paribus, an increase of one percentage point in unemployment would decrease property prices by 4.3% and an increase of one percentage point of the numbers of individuals with higher incomes raises house prices by 6.7%. For an increase of one percentage point of individuals with English as the primary language at home, house prices would reduce house prices by 0.2% which is unexpected in terms of sign but the parameter is small in magnitude. In other studies, access to local schools was shown to have a significant neighbourhood effect: this was explored but was not significant. School location is perhaps not such an important location issue in Sydney because NSW allows all students to travel free to all schools with the outcome that a very high number of school children attend schools ‘out of catchment’.

In terms of car and public transport accessibility, greater travel time implies worse accessibility and vice versa. If accessibility improves then, ceteris paribus, the estimated parameters should be negative as one more minute of car/public transport travel time (implying less good accessibility) is expected to lower property prices. Of the accessibility variables in the global regression, three are significant and of the right sign showing a property with better motorway access, quicker access by public transport to shopping opportunities and quicker access by public transport to employment centres along the transitway attracts a higher price. Ceteris paribus, a one minute decrease in access time to a motorway adds 4.2%, a one minute decrease in access time to a shopping centre adds 0.7% and a one minute decrease in access time to employment along the transitway adds 0.7% to house price. At the mean, a one minute saving in car access to a motorway equates to approximately 30% saving from the average time (see Table 1) and generates a house price premium of approximately $9,550 (4.2% of the mean price, see Table 1). For public transport accessibility, a one minute saving at the mean equates to an 8% time saving in accessing a local shopping centre and an 3% time saving in accessing one of the two employment centres located on the transitway with both giving an uplift in house price of $1591 (0.7% of the mean house price). The accessibility variable, BUS MAJORCENTRE, measuring the shorter of the travel time to either Liverpool or Parramatta is not significant in this global regression.

Houses located within 100m of the transitway, ceteris paribus, experience a statistically significant decline in house price, relative to those beyond of 9.2% which, at the mean, is $20,923.
6.2 GWR local model estimation

As identified above, one key advantage of GWR modelling is the opportunity to visualise the spatial variability of independent variables used in the estimation process. Some independent variables therefore might be non-significant in the global regression model but might vary significantly over the geographical area and be revealed as significant local parameters by the GWR modelling and vice versa.

<table>
<thead>
<tr>
<th></th>
<th>Significance level for spatial variability (p value)</th>
<th>Significance level in global regression (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>BEDROOMS</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>BATHROOMS</td>
<td>0.05000</td>
<td>0.000</td>
</tr>
<tr>
<td>PARKING</td>
<td>0.91000</td>
<td>0.000</td>
</tr>
<tr>
<td>UNITBED</td>
<td>0.03000</td>
<td>0.000</td>
</tr>
<tr>
<td>ENGLISH</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>UNEMP</td>
<td>0.39000</td>
<td>0.000</td>
</tr>
<tr>
<td>INCOME</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>ACCESS_MOTORWAY</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>BUS_MAJORCENTRE</td>
<td>0.00000</td>
<td>0.112</td>
</tr>
<tr>
<td>BUS_SHOP</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>BUS_EMP</td>
<td>0.00000</td>
<td>0.000</td>
</tr>
<tr>
<td>100mBUFFER</td>
<td>0.08000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Figure 2: Maps for the local model estimates of the accessibility variables for the Liverpool Parramatta transitway.
The GWR software provides diagnostic information to assess whether the local model is an improvement over the global model described above. In this analysis, the local model benefits from a higher adjusted coefficient of determination (adjusted $R^2$) from 0.64 to 0.76 and a lower AIC (from -764 down to -1256) suggesting that the GWR local model gives a significantly better explanation, after taking the degrees of freedom and complexity into account. The GWR software provides a Monte Carlo significance test procedure to examine the significance of the spatial variability of parameters identified in the local parameter estimates. The results of these tests, shown in Table 3 below, demonstrate that there is highly significant variation (at the 5% level or better) in the local parameter estimates for all variables except PARKING, UNEMP and the 100mBUFFER which do not vary in a statistically significant way over space.

Before turning to the accessibility variables in the local regression, it should be noted that the variable ENGLISH, noted as statistically significant but of the wrong sign in the global regression above, is shown to be spatially varying by the Monte Carlo test in Table 2. A map of the local parameter estimates for ENGLISH show areas of statistically significant positive house premia (as expected) as well as some negative premia. This explains the average result displayed above in the global regression.

The results for the four accessibility variables are mapped in Figure 2 to examine their spatial variability. Whilst all the variables of the local model could be mapped, only the accessibility variables are mapped here because of this paper’s focus on the impact of accessibility on house prices.

In each of the maps, the background shading indicates where the local parameters are significantly different from zero with a t-value $>|2|$. The values of the local parameters have been coloured so positive values are shades of red whilst negative values are shades of blue. It is clear from the maps that the parameters demonstrate considerable spatial variation.

For BUS_MAJORCENTRE, which is the smaller of the bus travel times to Liverpool or Parramatta, there is a clustering of significantly negative values around the outskirts of Parramatta and the Woodpark/Warren part of the transitway (see Figure 1) where statistically significant premiums of between 2-3.7% can be observed for each minute of travel time saved. At the mean value this equates to a premium of between $4,549 and $8,415.

For BUS_EMP, the map shows an area with statistically significant local accessibility to employment along the transitway around Brown on the transitway (see Figure 1) with house price premiums of up to 1.7% for a minute saving in travel time. At the mean value this equates to a premium of up to $3,866. Close to the Parramatta terminus and in the Hoxton Park part of the transitway (see Figure 1) there are negative premia associated with accessibility to employment on the transitway. In both cases, it maybe because the house locations are closer to the major centres of Liverpool and Parramatta so that accessibility to employment along the transitway does not add to house prices.

Access to a local shopping centre, BUS_SHOP, shows greater areas of positive premia of up to 3.8% for a saving of one minute travel time by bus. This equates to up to $8,642 at the mean. This map also shows negative premia around the local shopping facility in Parramatta itself. This shopping centre is adjacent to the rail and bus interchange and maybe more to do with noise and traffic exposure.

The accessibility of car, as a competing mode, to motorway access (ACCESS_MOTORWAY) shows spatially varying house premia of up to 4.9% for a one minute saving in travel time along parts of the transitway. This equates to $11,144 at the mean. In the centres of Parramatta and Liverpool, there are negative premia suggesting accessibility by car to motorways does not add to house prices there.

In each of these maps, where statistically significant house price premia are identified, they are considerably stronger than is indicated by the global regression. For BUS_EMP, the global regression estimated parameter suggests a house price premium of 0.6% on average but the
GWR local model identifies statistically significant premia of up to 1.7%. For BUS_EMP, the global regression estimated parameter suggests a house price premium of 0.6% on average but the GWR local model identifies statistically significant premia of up to 1.7%. For BUS_SHOP, the global regression estimated parameter suggests a house price premium of 0.7% on average but the GWR local model identifies statistically significant premia of up to 3.8%. For ACCESS_MOTORWAY, the effect is less strong with the global regression estimated parameter suggests a house price premium of 4.2% on average with the GWR local model identifying statistically significant premia of up to 4.9%. For BUS_MAJORCENTRE, the global regression estimated parameter value is not statistically significantly different from zero but the local model identifies areas where this relationship is statistically significantly different from zero with both negative and positive house price premia. Although some of the areas of local statistical significance are small, the potential presence of multicollinearity in the local model may well have underestimated the spatial areas where statistically significance can be identified.

**Conclusion**

The global model, as a hedonic model, explains the average impact of accessibility on house prices whereas the GWR local modal offers the opportunity to see the variability in premia. In particular, the results show the transitway appears to have met the aim of its introduction which was to facilitate access to shopping and employment facilities along its route. This evidence on value uplift for bus related infrastructure investments confirms results found in other places in the developed world: accessibility improvements do add to house values but not dramatically. In addition the empirical analysis confirms that properties can be too close to public transport infrastructure with negative uplift being associated with the negative externalities of noise and environmental pollution.

The standardised variable results from the global regression suggest that property prices are mainly determined by the internal features of the property and its neighbourhood effects. This is in line with other reported research estimating residential value uplift. Nevertheless, accessibility by car and accessibility to employment along the transitway are also contributing in a non-marginal way.

The local model shows that accessibility and its value have a geographical component which is significant. Inferring policy from a single, average, global value might well be misleading. Indeed the results demonstrate the benefit of undertaking a more disaggregate analysis that allows variation over space to be revealed. As identified in the introduction, this paper was motivated by a desire to understand whether land value capture could be used to fund bus related infrastructure investment. The analysis has demonstrated significant spatial variation in accessibility benefits suggesting a uniform land value capture tax would give rise to significant winners and losers.

**References**


Assessability and residential land value uplift: Identifying spatial variations in the accessibility impacts of a bus transitway

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Available at SSRN: http://ssrn.com/abstract=1753302


