Environmental Amenities and Local Development in Australia: Spatial Hedonic Pricing and Regional Economic Models

by

Parvin Mahmoudi

BEc (Hons), Faculty of Economics, Allameh Tabatabai University, Tehran/Iran

MEc, School of Economics, The University of Adelaide

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To my beloved parents, Nasser and Betty

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Abbreviations

2SLS	Two-stage Least Squares
ABS	Australian Bureau of Statistics
ASD	Adelaide Statistical Division
AU$	Australian Dollar
BOM	The Australian Government Bureau of Meteorology
GIS	Geographic Information System
GM	Generalised Moments
GS3SLS	Generalised Spatial Three-Stage Least Squares
GWR	Geographically Weighted Regression
i.i.d.	Independent Identically Distributed
IV	Instrumental Variable
LGA	Local Government Area
LM	Lagrange Multiplier
ln	Natural Logarithm
MDB	Murray Darling Basin
NDVI	Normalised Difference Vegetation Index

MLE	Maximum Likelihood Estimation
NSW	New South Wales
OD	Origin Destination
OLS	Ordinary Least Squares
QLD	Queensland
RESET	Regression Equation Specification Error Test
RP Data	Residential Property Data
SA	South Australia
TOM	Time on Market
Vic	Victoria

ABSTRACT

Many Australian cities are under pressure to preserve open spaces and limit suburban sprawl while still providing affordable and desirable housing and encouraging economic growth. In their efforts to preserve open spaces, public policy decision makers, require reliable information on the dollar value of open spaces. Moreover, the Millennium Drought (1997-2009) in regions across Australia, coupled with poor water allocation decisions, has seen a dramatic increase in the share of water diverted to the agricultural and urban sectors, leaving less water to flow into the natural environment. This has led to degradation of wetlands and water-dependent environment in some regions (*e.g.* Murray Darling Basin (MDB). The present study provides evidence on the local economic role of environmental amenities in urban and rural areas of Australia from two major strands of empirical research, respectively, hedonic pricing and regional economic models. Only economic analyses relying on well-established statistical techniques, reliable and extensive data and well-framed research methodologies can provide evidence about the economic value of environmental amenities.

As part of the development of a methodology to estimate the value of environmental amenities in Adelaide, the capital city of South Australia (SA), we review the literature of hedonic price models with reference to the theoretical foundations and empirical developments of the hedonic price method. The hedonic price model is commonly applied to estimate environmental attributes. The hedonic models are constructed using real estate data on property characteristics and selling prices. Spatial data on environmental amenities and locational attributes are also incorporated into hedonic pricing models. This literature suggests there is economic value on open spaces in urban areas. However, estimated values vary widely across studies which in turn create complexity to generalise results from this vast literature on open space valuation. Policymakers at all levels of government may find it difficult to use the extant literature for assigning a specific dollar value to a particular open space project. We estimate a spatial hedonic pricing model with fixed effects, to produce unbiased

and consistent estimates of the value of environmental amenity in Adelaide, SA. Such estimates will be important in placing a value on the economic benefits of residential and environmental amenity and provide support to planners and add quantitative values to the public policy debates.

The results indicate that the value of a property increases in proximity to green space sporting facilities, golf courses or the coast, (adding $1,580, $540 and $4,990 per kilometre closer respectively). The large urban Parklands in Adelaide add $1,550 to a property's value for each additional kilometre closer. This translates to an increase in the tax base associated with the Parklands given the number of properties within close proximity to the Parklands. We also present evidence of the importance of maintaining open space in a green and healthy condition in the current climate of water restrictions.

The presence of environmental amenities has also been shown to have a positive effect on people's quality of life in suburban and rural areas. We use a regional economic development in particular a generalised spatial three-stage least square procedure to evaluate the effect of environmental amenities on percentage changes in population, employment and income of 153 local government areas (LGAs) in the MDB, Australia. Estimates from the structural parameters, after accounting for spatial dependencies, show that environmental amenities have a significant role in enhancing economic development in the MDB. Areas closer to rivers experience more population increase over the period of 2001-2006 and LGAs closer to forests and lakes experience more employment and income growth. Additionally, rapid employment and income growth occur in areas with more rainfalls and higher temperature.

DECLARATION

I, Parvin Mahmoudi certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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1. Introduction

The present study provides evidence on the local economic role of environmental amenities in urban and rural areas of Australia, respectively, from two major strands of empirical research, hedonic pricing and regional economic models.

Australian cities are under pressure to expand in response to increased demands for urban living. The recent population debate in the Australian federal election 2010 and subsequent establishment of a Federal Minister for Population (Burke 2010) suggests there is some political commitment to exploring different population scenarios. Many Australian capital cities have long-term plans for urban development with the intent of guiding public policy and private investment toward sustainable development. These plans contain particular emphasis on the preservation of residential and environmental amenity (*e.g.* open space) from a broad perspective of human wellbeing and better livelihoods (State Government of Victoria 2010; Government of South Australia 2010). Setting aside and maintaining open space is a significant opportunity cost to public authorities and private developers.

Existing long-term development plans provide a clear indication of the pressures to be placed on urban and peri-urban environments for more housing and, as a corollary, less amenity and open space. For example, the NSW Government's (2010) strategy Sydney Towards 2036 recognises the need for an additional 770,000 homes in Metropolitan Sydney by 2036, a third of which will be in outer Sydney and the remainder will be met via infill. The State Government of Victoria's (2010) Melbourne 2030 long-term plan for Melbourne and the surrounding region forecast a population of five million before 2030. A key feature of the plan is the need for an additional 600,000 new homes by 2030, with nearly 50 per cent in outer Melbourne. The Queensland Government (2009), in its South East Queensland Regional Plan 2009-2031, forecasts an additional 160,000 dwellings required for the Brisbane area by 2031. The Government of South Australia (2010) in its 30-year Plan for Greater Adelaide forecasts the need for an additional 258,000 dwellings by 2040.

Urban development to accommodate the projected additional dwellings that are likely to be required in the coming two or three decades will involve increasing urban density via infill and consolidation and expansion of urban boundaries into peri-urban land. Robust planning coupled with market-based instruments and under-pinning regulations will be needed to minimise adverse outcomes. Placing a value on the economic benefits of residential and environmental amenity provides support to planners to evaluate the need for open space such as parks, reserves and wetlands within suburbs (Morancho 2003; Siedl *et al.* 2004; Tapsuwan *et al.* 2009; Poudyal *et al.* 2009; Bark *et al.* In press). Local governments, who are primarily responsible for regulating urban development, need information on the value of open space if optimal public provision of these areas is to be achieved.

This study provides estimates of the value of open space as revealed by the choices of homebuyers through real estate markets (the hedonic price method). The hedonic pricing method has been a substantial but indirect driving factor in environmental policy decision making. Palmquist and Smith (2002) discuss how the hedonic method has been part of environmental policy evaluations as well as public litigation. According to Palmquist and Smith (2002), policy uses of hedonic results often involve ex ante application of results derived under different situations, whereas hedonic studies for litigation involves ex post estimation of damages (*e.g.* hazardous waste contamination) at a specific location. They state that the use of hedonic property value models to provide information in developing environmental policy was accepted almost from the mid-1960s (at the time of the Ridker 1967 paper) before the existence of the U.S. Environmental Protection Agency and before major federal environmental legislation. Palmquist and Smith (2002) indicate that while the role of hedonic property value models in designing environmental public policy has been substantial, it has been indirect. This distinction does not mean the models have not affected the policy debate.

Environmental policy can no longer be designed without analyses of the full economic costs and benefits. Hedonic analyses of the effect of environmental disamenities on people and their property have had more success in litigation. Property values change in response to environmental disamenities because people actually pay to avoid environmental disamenities when they are discovered.

The hedonic pricing technique has also been a driving tool in pro-active policy planning. One area of policy decisions of particular interest is urban planning. Growth in residential development has been a concern around the world over the last few decades. On the one hand, people desire to live in an area surrounded by more open, green and natural spaces. On the other hand, residential development itself threatens these open spaces. The existence of public open spaces within urban environments potentially offers a significant number of economic, social and environmental benefits to communities. Policy decision-makers are faced with challenges in deciding where to protect or create green space, what type it should be and how to do it economically and politically. Understanding the direct economic impacts of urban green areas on neighbouring properties has become essential for public urban planning policies.

As part of the development of a methodology to produce estimates of the value of environmental amenity in Adelaide, the capital city of SA, we review the literature of hedonic price models with reference to the theoretical foundations and empirical developments of the hedonic price method. The hedonic models are constructed using real estate data on property characteristics and selling prices. Spatial data on environmental amenities and locational attributes are also incorporated into hedonic pricing models. This literature suggests there is economic value on open spaces in urban areas. However, estimated values vary widely across studies which in turn create complexity to generalise results from this vast literature on open space valuation. Policymakers at all levels of government may find it difficult to use the extant literature for assigning a specific dollar value to a particular open space project. To produce unbiased and consistent estimates of the value of environmental amenity in the Adelaide metropolitan area, we estimate a spatial hedonic pricing model with fixed effects. Such estimates will be important in placing a value on the economic benefits of residential and environmental amenity and provide support to planners and add quantitative values to the public policy debates.

In this study, a spatial econometric approach is taken to value residential amenities and environmental attributes in the Adelaide metropolitan area. We draw on the generalised spatial hedonic price model with fixed effects developed by Lee and Yu (2010). Extending Kong *et al.* (2007), Seong-Hoon *et al.* (2008) and Bowman *et al.* (2009), we use real estate data, Geographic Information System (GIS) data layers, remote sensing techniques and additional layers such as public transportation to build a geographically extensive and complex spatial dataset to estimate the value of environmental quality for a residential housing market. The result is a rich and extensive set of implicit price estimates of the structural housing, neighbourhood and amenity characteristics. Our findings can support decision-making and add quantitative values to the public policy debates.

In addition to evaluate the economic role of environmental amenities in urban area using a spatial hedonic pricing model, we investigate the influences of environmental amenities on regional economic development in the Murray Darling Basin (MDB), Australia with a regional economic model. The MDB, a one million square kilometre watershed, is situated in the south eastern part of Australia in states of New South Wales (NSW), Queensland (QLD), Victoria (Vic) and South Australia (SA). The Millennium Drought (1997-2009), coupled with poor water allocation decisions, has seen a dramatic increase in the share of water diverted to the agricultural and urban sectors, leaving less water to flow into the natural environment. This has led to degradation of wetlands and water-dependent environment in the region, some of which have global significance (*e.g.* Ramsar wetlands). The Howard (2008) study on the future of the Murray River highlighted the need for a comprehensive assessment to better understand environmental amenities. Moreover, in late 2010, the Australian government released the Guide to the Murray-Darling Basin Plan, which is a basin-wide framework for managing water resources. A key motivation is to raise awareness that a healthy MDB environment is vital for healthy local economies and communities (Murray-Darling Basin Authority 2011). With growing political awareness of the importance of a healthy environment contributing to regional economic development there is a need for economic assessments on which to base public policies to sustain environmental amenities which in turn generates economic development.

In this study, we evaluate whether environmental amenities, such as forests, major perennial rivers and lakes and natural parks influence the percentage changes in population, employment and median income of 153 local government areas (LGAs) in the MDB. This is to determine whether changes in population, employment and income are driven by the existence and proximity of environmental amenities in the local area. In order to capture the unobserved spatial dependencies, we estimate a model of simultaneous system-of-equations using the generalised spatial three-stage least square (GS3SLS) procedure.

2. Literature Review of Hedonic Property Value Models for the Valuation of Environmental Amenities and Disamenities

Many environmental amenities and disamenities are not directly traded in private markets, therefore estimating the associated benefits and costs can be difficult. To place a monetary value on the non-market environmental attributes, economists have used two broad methodological approaches, namely, stated and revealed preference techniques. Stated preference techniques rely on survey methods to elicit individual preferences and values for environmental attributes. As stated preference techniques involve directly asking individuals for their preferences and are based on hypothetical situations, they have been criticised for potentially containing several biases (Carson *et al.* 2001). However, revealed preference techniques use observed market choices that individuals make to reveal their underlying preferences and values for goods and services. The revealed preference approach enables the value of amenities/disamenities for which markets do not exist to be estimated through the use of information from related markets.

One revealed preference technique of particular interest is the hedonic pricing method. The technique has been applied to a diverse range of goods and used in many different fields. The hedonic method is most often used to value environmental attributes that directly affect the market price of residential properties. If the environmental variable of interest can be measured accurately, the hedonic pricing technique is relatively straightforward to apply, because it is based on actual market prices and fairly easily measured data.

When a household purchases a house, it implicitly buys an entire bundle of environmental attributes. A residential house can be considered as a multi-attribute good with the set of land and house structural, locational and environmental attributes. The land and the house structural characteristics can include the land area, presence of a swimming pool, garage, garden, building area, number of rooms, number of bathrooms, age of the building and condition of the house. The location attributes can include the distance to a central business district, distance to schools, *etc.* The environmental attributes can include proximity to parks, water and air quality, noise and a scenic view, as well as a variety of other attributes. If non-environmental factors are controlled for, any remaining difference in price can be attributed to differences in environmental attributes. Using regression techniques, the hedonic pricing method identifies what portion of property value differences can be attributed to the environmental differences and infers an individual's willingness to pay for those differences.

The purpose of this chapter is to review the development of hedonic techniques in environmental economics. To begin, we outline theoretical foundations and empirical developments of the hedonic price method. Prior literature that emphasise theoretical and welfare issues associated with hedonic pricing models can be found in reviews by Palmquist (1991), Haab and McConnell (2002), Taylor (2003; 2008), Freeman (2003), Palmquist (2005) and Bockstael and McConnell (2007). Prior reviews of the empirical literature include Ball (1973), Smith (1977), Freeman (1979a), Witte and Long (1980), Boyle and Kiel (2001), Palmquist and Smith (2002) and Pearce *et al.* (2006). This number of reviews indicates the vast size of the literature.

This chapter outlines the theoretical foundations and empirical developments of the hedonic price method. The main focus is to review the empirical studies in which the hedonic technique is applied to estimate the effects of open space on residential housing values. This chapter also reviews the papers that use hedonic price models to value the environmental disamenities and amenities.

2.1 Theoretical Foundations of the Hedonic Price Method

Lancaster (1966) builds an implicit theoretical foundation for empirical estimates of hedonic housing price equations. He defines consumer's utility as a function of the heterogeneous sets of characteristics of a product rather than the product itself. An example of a single product includes a house possessing structural, neighbourhood and environmental characteristics, which in turn drive a buyer's utility.

Lancaster provides an implicit theoretical base for the empirical implementation of the hedonic pricing method but this theoretical foundation has not been thoroughly explored or indeed closely followed in most empirical studies. This is due to the Lancaster's assumption of a linear relationship between the price of products and their characteristics, which implies constant implicit prices over ranges of characteristics quantities. In contrast, Rosen (1974) assumes a nonlinear price function that relates the equilibrium market price of a product to the quantities of the characteristics associated with the product depending on the best fitting functional form of the price equation. Rosen's (1974) seminal article is an important theoretical contribution that forms the basis for much of the empirical works on housing markets using hedonic pricing models.

Rosen develops a model of the interactions of buyers and sellers in a competitive market for a product (*e.g.* house) that determines the equilibrium hedonic price schedule. The equilibrium is described by the intersection of demand and supply functions. The buyer's marginal value function reflects the inverse compensated demand function for a characteristic. The seller's marginal offer function reflects the profit-compensated supply function for a characteristic. Rosen's model consists of two related stages often, in the literature, referred to as first-stage and second-stage analyses. In the first stage, observed housing sales prices are regressed on all of their characteristics using the best fitting functional form to recover the marginal prices of housing structural, location and environmental characteristics. The first-stage develops a measure of the implicit prices, but does not directly reveal the inverse demand function (the marginal willingness to pay function). The second-stage estimation is to identify the marginal willingness to pay function. The estimated marginal hedonic prices are used as endogenous variables in the second stage to estimate the marginal bid and marginal offer functions simultaneously using individual seller's attributes affecting the marginal offer as instruments. However, this identification of the inverse demand function poses some problems because it depends on the assumptions made about the supply side of the implicit market for the attribute. If the supply curve is perfectly elastic, or if the supply of a characteristic is fixed, the marginal price of the characteristic becomes exogenous in the estimation of the inverse demand function.

Bartik (1987) criticised Rosen's approach for the estimation of demand parameters in hedonic price models (willingness to pay for function). Bartik points out that the hedonic estimation problem is not the result of the interaction between demand and supply because the individual buyer cannot affect the sellers. Instead, the hedonic estimation problem is caused by the endogeneity of both marginal prices and quantities when consumers face a nonlinear budget constraint. He also argues that Rosen's suggested instruments, individual producer's attributes, are not appropriate instruments for the endogenous variables, a vector of observed characteristics and composite goods, in the marginal bid function. This is because a producer's attributes are correlated with a consumer's choice of characteristics and composite goods and hence the error term in the marginal bid function produces biased results. As a solution to this problem, Bartik suggests an instrumental variable that exogenously shifts a consumer's budget constraints and is correlated with a consumer's choice of characteristics and composite goods yet uncorrelated with the marginal bid function error term.

Even today, the concept of a two-stage analysis raised by Rosen has not been entirely resolved. But without doubt his influential article was an important theoretical contribution that formed the basis for much of the empirical work on housing markets using hedonic pricing models.

Several authors continue to expand and develop Rosen's work, particularly in the area of second-stage analysis. In a first-stage analysis, the marginal implicit prices of environmental attributes are estimated. Once the first-stage analysis is completed, willingness to pay for environmental improvements can be estimated. In the second-stage, the estimated marginal implicit prices from the first stage in conjunction with the quantities of characteristics purchased and the socio-economic characteristics of purchasers are used to identify the underlying preferences.

Freeman's (1974b) paper, as important as Rosen's but cited less often, addressed the issues associated with the second-stage estimation: measuring willingness to pay from hedonic models. Both of Freeman and Rosen suggest two important insights associated with measuring willingness to pay for a marginal (one unit change) or non-marginal change in a localised or non-localised amenity.

The first insight is that the estimated hedonic price provides an estimate of the marginal willingness to pay for a marginal increase in environmental attributes for each household at the location they have chosen, which has been re-iterated by Taylor (2008). According to Taylor, in a hypothetical situation with no moving or transactions costs, the estimated hedonic price is only a measure of the net benefits of a change in environmental attributes if the change in environmental attributes is both marginal and localised. A marginal change in a localised amenity affects a relatively small number of properties and so would not shift the equilibrium hedonic price function for the entire market. For non-marginal but localised changes in environmental attributes, the net benefits can still be measured from the hedonic price schedule when there are no transactions or moving costs (Palmquist 2005; Taylor 2008). If the transactions or moving costs are very high so as to prevent households from moving or if households can move, but homes identical to their existing housing are not available, then the net benefits estimated from the hedonic price function represent an upper-bound of the net benefits (Palmquist 2005; Taylor 2008).

The second insight of Freeman (1974b) and Rosen (1974) is that estimates of willingness to pay for non-localised environmental changes are not available directly from the first-stage estimation of a hedonic price function. This is because environmental improvements would shift the hedonic price function (Polinsky and Shavell 1976; Polinsky and Rubenfeld 1977). For non-localised changes in environmental attributes, the second-stage analysis is required to derive the parameters of the consumer utility function.

Polinsky and Shavell (1976) developed a model to identify willingness to pay for both marginal and non-marginal environmental improvements in the case of a small-open urban area and a closed city. They defined a small-open city as one in which amenity changes do not influence prices in other cities and consumers' moving costs are zero because they are perfectly mobile. The authors defined a closed city as one in which household mobility is restricted to a given urban area. They indicated that property values at any location in the small-open city depend only on amenities at that location. For the case of a closed city, property values at any location depend on amenities throughout the city. The authors showed that the change in aggregate land values due to an amenity change would measure aggregate willingness to pay for the case of the small-open model only. If the area is small and moving costs are zero, amenity improvements cannot affect consumer utility. All benefits accrue to landowners in the improved area in property value increases. The hedonic price function can predict these property value increases because the function will not shift after a change in a small area.

Subsequently, Polinsky and Rubinfeld (1977) developed a method to calculate aggregate willingness to pay for an improvement in the environment regardless of whether the urban area was closed or open. They analysed the more general case of amenity improvements that affected the hedonic price function and hence consumer utility. They measured the immediate impact on consumers of a change in amenities before the urban area adjusts to a new equilibrium by identifying and estimating the utility function of each class of consumers. Their suggested procedure involved first, the estimation of the hedonic prices using observations from all locations occupied by consumers in class i. Second, they used the estimated parameters from the first step to estimate the utility function for consumer class i, which in turn was used to calculate each consumer's willingness to pay for a change in amenities. The authors estimated aggregate willingness to pay by summing willingness to pay over all locations and over all consumer classes i. They stated that the estimation of willingness to pay is probably a better approximation for marginal than non-marginal changes. Their reason was that no consumer was allowed to adjust to the changes in amenities.

The logic of Polinsky and Shavell (1976) and Polinsky and Rubinfeld (1977) can be used for a given urban area. That is, Palmquist (1992a) showed that willingness to pay for non-marginal environmental changes can be derived from the hedonic regression if the environmental change is localised. If an environmental change is non-localised, the environmental change shifts the hedonic price function. Housing demanders and suppliers may adjust their location and their supply decisions.

Bartik (1988) demonstrated that when all possible adjustments by housing demanders and suppliers were considered, the hedonic price equation still provides an upper bound for the benefits of amenity improvements under almost all circumstances. Interpreting the marginal price as a benefit measure relies on a household's adjustment condition. If a full selection of choice alternatives and costless adjustment are available to households, they will search over the available houses until their marginal willingness to pay for the environmental improvement is equal to the marginal price. Therefore, the hedonic price function describes the marginal prices of environmental attributes. Also it reveals a point on the marginal willingness to pay schedule but it does not reveal the full marginal willingness to pay schedule.

If the assumption of a full selection of costless adjustments available to households is relaxed, the estimation of the net benefits of a non-localised amenity change requires knowledge of the parameters of the consumer utility function. Deriving such parameter estimates requires the hedonic second-stage analysis.

Identification of the parameters of the consumer utility function is usually achieved by either using multiple markets or a single market. In the multiple markets approach, an assumption is made under which the consumers have homogeneous preferences across different markets, but differences in supply conditions result in different marginal prices across markets. In this case, estimating separate hedonic price functions in each market would identify the demand function. Bartik (1987), Epple (1987), Palmquist (1984), Boyle *et al.* (1999), Palmquist and Israngkura (1999) and Zabel and Kiel (2000) are examples of studies which have used multiple markets to identify the parameters of the consumer utility function.

An alternative identification strategy is to use a single market. Identification of the preference function within a single market requires some restrictions on the functional form of the hedonic relation. The reason is that the marginal prices of housing characteristics are deterministic functions of a set of attributes of houses. They contain no information about consumers' valuations beyond that contained in the observed sample of attributes. Quigley (1982) investigates how specific restrictions can be used to identify the functional relationship. He indicates that the assumptions about the form of the preference function imply practically no meaningful restrictions on the functional form of the hedonic function, in a world where market prices are demand determined. With demand determined prices, the exact shape of the hedonic function cannot be worked out without detailed information on the distributions of income and housing attributes. However, if the hedonic function is given exogenously, or if it is estimated according to some systematic statistical criterion, it is possible to estimate the demands for housing attributes.

The multiple-market approach has traditionally been viewed as a more acceptable approach for identifying the parameters of the consumer utility function because single-market approaches require tight parameterisation of the hedonic model. However recent research (Eckland *et al.* 2002a; 2004; Bajari and Benkard 2005; Bajari and Kahn 2005) has adopted the single-market approach to estimate demand parameters and assumed consumer heterogeneity.

Eckland *et al.* (2002a; 2004) indicate that marginal prices are nonlinear functions of characteristics therefore the variation in estimated marginal prices can be used to identify preference parameters. As such, the hedonic model is non-parametrically identified within a single market and nonlinear instrumental variables or transformation model methods demonstrate how preference parameters can be identified.

These approaches have all contributed to the development of hedonic price methodologies, particularly that of second-stage modelling. While Lancaster (1966) provided an implicit theoretical base for empirical estimates of hedonic housing price equations, it was Rosen's (1974) influential article on product differentiation and competition that formed the basis for much of the empirical work on housing markets using hedonic pricing models. Subsequent researchers have highlighted the importance of second-stage analysis to derive the parameters of the consumer utility function for measuring willingness to pay for non-localised changes in environmental attributes. Identification of the willingness to pay function requires that there be sufficient information to distinguish the behavioural functions of individuals based on their utilities for houses and environmental attributes from both the equilibrium price schedule and the supply functions for these attributes. A variety of assumptions have been proposed about underlying utility functions and pooling information from multiple or single markets. It is worth noting that the complexity and data requirements of the second-stage analysis have limited the number of examples available in the literature.

2.2 Empirical Issues and Developments of the Hedonic Prices Method

For some types of benefit measures, it is only necessary to estimate the hedonic equations (first-stage analysis); in other cases, the hedonic equation is used to generate marginal prices which in turn are used to estimate the willingness to pay for environmental attributes (second-stage analysis). In either case, the estimates for the hedonic function must be reliable. The many different econometric issues, such as functional form for the hedonic price function, market size and other empirical issues that must be addressed to obtain robust estimates are briefly discussed in this section. We also review empirical advancements in hedonic studies.

The reliability of the results obtained using hedonic regressions also depends on the use of the correct functional form. In theory, there are no straightforward indications for the functional form for the hedonic equation. This is because the hedonic price function is an envelope function. Unless there is costless repackaging of the characteristics of housing, in which case the hedonic price function is linear, the correct functional form cannot be determined theoretically. Therefore, it must be determined empirically. Such selection can be based on the procedure suggested by Box and Cox (1964), which is to maximise the Box-Cox log-likelihood function for the candidate functional forms.

The functional forms used widely in the literature immediately following Rosen's (1974) seminal paper include linear, semi-log, inverse semi-log and log-linear. In an influential paper, Halvorsen and Pollakowski's (1981) proposed the quadratic Box-Cox functional form. Their suggested functional form is a highly local flexible functional form that yields all other functional forms of interest as special cases. The quadratic Box-Cox functional form has a limitation, which is the same Box-Cox transformation applied to all the characteristics. According to Palmquist (2005), it is not acceptable to transform any or all of the environmental variables in the same way as the structural attributes.

This is due to the fact that the environmental variables often have minor impacts on property prices while the structural characteristics have the strongest influence. The incorrect transformation of environmental attributes could result in inaccurate estimate of willingness to pay for environmental improvements. He added that improvements in computer packages in order to assign different Box-Cox parameters for different attributes would be a significant step forward.

Cropper *et al.* (1988), following the influential paper by Halvorsen and Pollakowski (1981), suggested if a researcher's goal is to value product attributes, then the functional form that measures the marginal attributes prices accurately must be selected. They conducted Monte Carlo experiments to determine the accuracy of the estimated marginal prices for different functional forms of the hedonic price functions. The authors' simulations suggested if all attributes are observed, the linear and quadratic Box-Cox functional forms provide the most accurate estimates of marginal attributes prices. However, if some variables are not observed, or are measured by proxies, which happens often in empirical studies, the simpler linear and semi-log forms and linear Box-Cox outperforms the quadratic Box-Cox function.

In recent studies, the most common functional form for hedonic price equations is semi-log and often independent variables are also transformed with natural log or quadratic terms, which is the Box-Cox transformation of both sides (Taylor 2008). Taylor indicates that the Box-Cox transformations have several limitations. First, researchers are usually interested in the conditional mean of price, not the conditional mean of transformed price. Second, the Box-Cox estimators will be inconsistent if the transformed price does not follow a normal distribution.

The reliability of the results obtained using hedonic regressions also depends on the appropriate size of the market. The hedonic price schedule represents the equilibrium price schedule in a market. Thus, researchers must know the geographic extent of the market when they conduct environmental hedonic studies. On the one hand, if the researcher assumes that there is a single housing market when it is actually segmented, the estimated coefficients will be biased. On the other hand, if the researcher assumes that the markets are segmented when they are not, the estimates will be imprecise and they may have insufficient variation in the environmental variable in each segment. Theoretical and empirical approaches may help researchers to define the extent of the market.

In theory, markets are considered separate if almost no purchasers in one segment participate in other segments (Freeman 1979b). Purchasers may not participate in other markets due to a barrier such as geography, discrimination or lack of information. Markets are also considered separate if the structures of supply or demand are different in the various segments (Freeman 1979b). Palmquist (1991) suggests market segmentation between urban areas may occur if information and moving costs between cities are large enough. He adds within urban areas the existence of discrimination can cause market segmentation; however environmental hedonic studies have never separated markets with respect to racial or ethnic variables.

The most common empirical method for identifying market segmentation is to apply F-tests to determine if the coefficients from various segments are equal. However, there exist some shortcomings associated with F-tests. The first problem is that F-tests are only reliable if the hedonic price function is correctly specified and there is no definite theoretical guidance for the specification of the hedonic equation. Therefore, F-tests' results indicating that markets are segmented may be due to misspecification of the hedonic equation and not segmentation (Taylor 2003). The other problem with this method is that F-tests will always reject aggregating market areas due to large sample sizes in hedonic studies.

Taylor (2003) indicates that there are no definitive answers to define the market extent. She suggests that a researcher can use his or her judgement along with empirical tests to determine the extent of the market. Palmquist (2005) states most economists today consider an urban area as a single market. The author adds that even if a researcher considers an urban area to be a single market, this does not mean a submarket cannot be used to investigate the price effects of environmental disamenities or amenities of interest. He refers to the advantages of using smaller areas if the environmental valuation can be calculated within that area (if there is enough variation in the environmental attribute of interest within the study area). One of the advantages is that a researcher can avoid the complexity of full specifications of all the important attributes that change within an urban area but not inside a smaller area.

One of the other empirical issues of hedonic studies relates to data. In early hedonic studies, researchers had access to information at the census tract level and usually included the average owner-estimated property value within the tract. Examples of such studies include Ridker and Henning (1967) Anderson and Crocker (1971) and Nelson (1978). In recent decades, the majority of hedonic studies use property information and sale prices at house-level, which are collected variously by the private and public sectors.

There are some problems with using sale prices as a dependent variable. One of the problems is that not all sales are "arms-length" transactions. Sales that are not "arms-length" transactions do not represent market values of properties; therefore it is not appropriate to include them in the hedonic analysis. A researcher must have a good understanding of the real estate market and remove sale prices that are too low. The other problem with using sale prices is the potential for sample selection bias.[1] Sample selection bias occurs if properties with particular unobservable attributes are not sold

[1] Sample selection bias, which happens often in empirical studies, is inevitable.

once placed on the market. Therefore these properties are not included in the data. In this situation, Ordinary Least Squares regression technique produces biased estimates.

The selection of independent variables is an important process in hedonic modelling. Independent variables include house and land characteristics, features of neighbourhood and a property's location. A researcher should investigate which variables within each category to include. On the one hand, including too many variables in a model if they are related to other independent variables can cause multicollinearity.[2] In this case, standard errors increase and hence the researcher fails to reject the null hypothesis of no significant price effect of an attribute when it actually affects price. On the other hand, researchers that use too few variables may end up with not including relevant variables, which would also bias the estimates. Taylor (2003) suggests "the researcher must thoughtfully develop a modelling approach, review related hedonic studies and test the robustness of results to assumptions regarding which variables to include whenever possible".

Measurement error in the independent variables is another empirical concern in hedonic applications. Measurement error in the environmental attributes is of particular concern. Objective or scientific measures of environmental attributes should be consistent with the subjective measures of those attributes by the market participants (*e.g.* buyers and sellers of a house). If not, they lead to biased estimates of all coefficients. In some cases (i.e. certain air pollutants), the objective measures may be highly correlated with what market participants perceive. In other cases, some transformation of the objective measure may be required to obtain a better proxy for the measures buyers and sellers place on a commodity. Palmquist (1991) suggests conducting surveys to

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[2] See Belsley, Kuh and Welsch (2005) for techniques to test for the existence of multicollinearity.

establish knowledge of the relationship between the objective measures and the average perception of residents.

Consideration of recent points of discussion in hedonic estimation, such as endogeneity, omitted variables and spatial autocorrelation, is an important aspect of developing a first-stage model that provides accurate results. While these issues are complex, recent advances in research have made them surmountable.

Endogeneity in hedonic price function estimation can arise from either omitted variables or the simultaneous determination of sales price and a regressor. An instrumental variable technique (IV) is often adopted to deal with the endogeneity issue (*e.g.* Irwin and Bockstael 2001; Irwin 2002) as ordinary least square (OLS) estimates would be both biased and inefficient. The IV method requires an estimation of the hedonic pricing equation by two-stage least squares estimators (2SLS) using appropriate instruments for the endogenous variable(s). The instruments need to correlate with the endogenous variable(s) but be uncorrelated with the error terms in the hedonic price equation.

Chay and Greenstone (2005) and Greenstone and Gallagher (2006) note that endogeneity due to omitted variables is likely caused by co-variation of the observed spatial attributes under study with unobserved spatial characteristics. Taylor (2008) makes an example of the case where endogeneity arises from simultaneous determination of sales price and a property's time on the market (TOM). She defines sales price as a function of TOM and a vector of all other variables affecting sales price. The author also defines TOM as a function of sales price and all other variables influencing TOM (*e.g.* commission paid to agents). The estimation of the sales price function without considering the endogeneity of TOM results in inconsistent estimates.

Taylor (2008) indicates that in a first-stage hedonic regression, endogeneity in housing attributes cannot arise from simultaneous determination. This is because households' location decisions are along the hedonic price function. For example, building area is not endogenous in a first stage regression because individuals who choose bigger houses pay higher total prices, all other things being equal. However, endogeneity of a building size could arise due to its correlation with an important omitted variable.

Perhaps the most common assumptions in hedonic studies have been the independency of any omitted variables from the regressors and also that omitted variables only introduce spatial autocorrelation (Taylor 2008). Spatial autocorrelation is also called spatial error dependence or a spatially dependent error term. Spatial autocorrelation implies dependency across observations in cross-sectional data. With spatial autocorrelation, the error term for a house can be correlated with the error terms for houses in a multitude of directions. Spatial autocorrelation is much more complicated than autocorrelation with time-series data. With time-series data, the autocorrelation is one-dimensional (the time dimension) and it may be uni-directional (the past events may affect current events but not vice versa). But with cross-sectional data, the problem is at least two-dimensional and may be bidirectional as the natural ordering over time is not available spatially.

There is another concept in spatial econometrics, which is spatial autoregression. Spatial autoregression is also referred to as spatial lag dependence, structural spatial dependence, or a spatial autoregressive dependent variable process (Anselin and Bera 1998). With spatial autoregression, the prices of some neighbourhood properties affect the price of any given property.[3] In the literature, spatial autocorrelation has been of more concern than spatial autoregression.

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[3] See Anselin (1988), Anselin *et al.* (1995; 1996; 1998) for general models of spatial autocorrelation and spatial autoregression.

According to Taylor (2003), Lagrange multiplier tests, Moran's *I* statistics (Anselin 1988a) and Kelejian and Robinson tests (Kelejian and Robinson 1992) may be used to test for the existence of spatial autocorrelation or spatial autoregression. A researcher can use software packages for spatial data analysis such as SpaceStat, GeoDa and Stata to conduct these tests.[4] Given evidence of spatial autocorrelation or spatial autoregression, the researcher must specify spatial weights matrices.

The most common specification of the weights matrix is distance-decay matrices. With this structure, the importance of each house on the house of interest decays as distance increases. Alternative structures, such as a lattice matrix in which elements of the spatial weight matrix are equal to one if two properties share a border or are within a certain distance of each other, are also used. Specification of the spatial weights matrices is highly controversial in spatial econometrics as the cross-sectional data by nature is multi-dimensional (Taylor 2003; 2008). Once the researcher has specified spatial weights matrices, he or she can estimate the models using maximum likelihood or generalised moments estimators (Taylor 2003).

With many of these empirical concerns addressed in the development of first stage hedonic models, the parallel development of GIS and its application to hedonic research has made the hedonic pricing model a powerful tool. This spatially referenced tool is extremely useful in developing environmental policy when it is used to enhance methods of valuing environmental attributes.

Chang (2002) defines a GIS as a computer system for capturing, storing, querying, analysing and displaying geographically referenced data. There is a long history of including distance from a

[4] SpaceStat and GeoDa softwares are free to download. SpaceStat can be downloaded at www.spacestat.com and GeoDa at http://geodacenter.asu.edu/software/downloads.

property to a disamenity or amenity as an explanatory variable in hedonic price models. In the earliest studies, the researchers measured distances by a ruler. The adaptation of computers has greatly enhanced GIS capabilities. In recent years, GIS has facilitated measuring such distances and added an additional dimension to model specifications. GIS data have enhanced the ability of hedonic price models to explain variation in sale prices by considering both proximity and extent of environmental attributes. One of the most basic advantages of GIS is to position properties on a local map in terms of their geographic coordinates (Kong *et al.* 2007). In many studies there may be multiple types of amenities and/or disamenities proximate to properties and based on digitised remote sensing data within GIS it is possible to efficiently generate variables to distinguish them. The generated variables include size and shape of environmental attributes, the ratio of size to distance from a property, diversity, aggregation and fragmentation of land uses in various buffer sizes around residential properties, the ease of accessibility to environmental attributes and information on topography.

The other advancement in the hedonic pricing approach is the integration of other disciplines such as landscape ecology with environmental resource economics. Joint ecological and hedonic modelling based on GIS has made a large contribution to the valuation of environmental attributes. One aspect of the contribution is that landscape ecologists are able to quantify spatial pattern by creating and developing landscape indices within GIS (*e.g.* Kong *et al.* 2007). This feature increases the explanatory power of the hedonic equation which in turn enriches the empirical model.

Our brief review of the empirical issues and advancements in hedonic studies provides a valuable context for our empirical hedonic study, which is the valuation of environmental qualities in particular open spaces in the Adelaide metropolitan area, South Australia. Details on real estate data are provided in Section 3.1.2.1. Sections 3.1.2.2 provides details on the construction of distance matrices to neighbourhood and environmental qualities within GIS.

Subject to a Box-Cox test for functional form and a Ramsey F-test, we estimate a hedonic price model with the specification involving 65 variables in a double log functional form with respect to the dependent variable and all the distance metrics to the attributes of environmental quality. This formulation of the house, land and neighbourhood characteristics is consistent with the approach in the literature (Cropper *et al.* 1988; Taylor 2003).

Hedonic studies often assume the independency of any omitted variables from the regressors and that omitted variables only introduce spatial autocorrelation. We used Moran's *I* test statistics to test for spatial autocorrelation and estimated the hedonic price model using maximum likelihood estimators (see Section 3.1.4 for more details).

2.3 Explored Durable/Nondurable Goods and Environmental Attributes

Numerous empirical studies have estimated hedonic prices for characteristics of durable goods. Types of durable goods studies include automobiles (Griliches 1961; Triplett 1969), tractors (Pagoulatos 1982) and computers (Dulberger 1989). Hedonic pricing techniques have also been used to estimate implicit prices for characteristics of nondurable goods such as breakfast cereals (Morgan *et al.* 1979; Stanley and Tschirhart 1991).

The hedonic pricing method, however, is most commonly used for the purposes of non-market/implicit valuation of environmental attributes. Before heading toward hedonic property studies for the valuation of the environmental amenity of interest, open spaces, which are presented in Section 2.4, a brief review of the studies that use this method to value environmental attributes provides a context for our study.

The value individuals have for environmental attributes are not observed directly but determined implicitly from observable real estate market transactions, which is called the hedonic pricing method. When a household purchases a house, it implicitly buys an entire bundle of environmental attributes. A residential house can be considered as a multi-attribute good with the set of land and house structural, locational and environmental attributes. The land and the house structural characteristics can include the land area, presence of a swimming pool, garage, garden, building area, number of rooms, number of bathrooms, age of the building and condition of the house. The location attributes can include the distance to a central business district, distance to schools, *etc.* The environmental attributes can include water and air quality, noise and a scenic view, as well as a variety of other attributes. The differences in market prices of houses that share identical characteristics can possibly be explained by environmental factors, which have no explicit market values.

In the literature, reviews exist based on a specific environmental disamenity or amenity. Nelson (1980) reviews 13 empirical hedonic studies of airport noise and property values at 18 different airports. Nelson (1982) also reviews highway noise. Smith and Huang (1995) review 37 studies carried out between 1967 and 1988 in which the hedonic technique is applied to value an air quality improvement in certain cities in the USA. McConnell and Walls (2005) review more than 60 published articles that attempt to estimate the value of different types of open space.

In the hedonic literature, Ridker (1967) is often credited with the first hedonic price estimate. In the mid-1960's, the Division of Air Pollution in the U.S. Public Health Service became interested in the costs of air pollution (Palmquist and Smith 2002). Arguably the most important part of that project was the property value study, which provided the basis for the influential article by Ridker and Henning (1967). Ridker and Henning (1967) successfully applied a hedonic approach to determine the housing price effects of variations in air pollution levels using cross-sectional data at the census tract level within St. Louis, Missouri in 1960. The results indicated that the air pollution variable was significant and had a negative impact on values of residential properties in the St. Louis metropolitan area. Their paper generated a significant literature on using hedonic property value models to reveal the value placed on environmental attributes. Since then, the idea of using hedonic property value models for the valuation of environmental attributes has become firmly established in the field of environmental resource economics.

Hedonic approaches have also been successfully used to determine the value of other non-market environmental attributes. For instance, Kiel and Zabel (2001) estimated the economic benefits of cleaning up superfund sites in Woburn, Massachusetts. Flower and Ragas (1994) examined the influence of large-scale oil and gas infrastructure on residential property prices. Boxall *et al.* (2005) estimated the impact of oil and gas facilities on rural residential property values. The results showed that oil and sour gas facilities within four kilometres of properties had a significant negative impact on their sale price.

This technique has also been used for more localised problems. Palmquist and Vukina (1997) conducted a hedonic study to determine the effect of large-scale hog operations on surrounding property values. They developed an index of hog production at different distances from the houses. Findings suggested that the proximity of hog operations had a significant negative impact on property values. However, the monetary losses reduced with the increased distance from the hog operations to the house. Results also showed that in high hog density areas, the expansion of hog operation will have a smaller negative impact on neighbouring housing prices than in low hog density areas.

Simons *et al.* (1997) mentioned more recent studies in which housing prices were related to underground water contamination, the existence of high power electric networks and hazardous waste landfills. Gawande and Jenkins-Smith (2001) examined the effects of the transport of hazardous wastes on residential land prices. The impacts of electricity transmission lines on residential land prices have also been investigated by Hamilton and Schwann (1995). Applications of the hedonic pricing method have also focused on the analysis of school districts (Clark and Herrin 2000), urban wetlands (Mahan *et al.* 2000), air quality (Zabel and Kiel 2000), water quality (Leggett and Bockstael 2000; Bastian *et al.* 2002) and urban revitalisation (Ding *et al.* 2000). The techniques are established and researchers increasingly use them to estimate environmental valuation in the hope of informing public policy debates.

2.4 Open Space

Since the influential paper by Ridker and Henning (1967), the idea of using hedonic property value models for the valuation of environmental attributes has become firmly established in the field of environmental resource economics. In early studies, the focus was more on the valuation of environmental disamenities. Gradually, this method has also been used to investigate the effects of environmental amenities such as open spaces.

The existence of public open spaces within urban environments potentially offers a significant number of social and economic benefits to communities. The social benefits provided by open space include recreation, scenic amenity, ecosystem services/amenity and tourism. Intuitively, the economic benefits provided by open space include an increase in surrounding house prices. However, intuition does not answer the question of 'by how much?'

The provision, maintenance and protection of public open spaces are receiving increasing attention by policy decision makers around the world. To conduct proper cost-benefit analyses of public urban planning policies, the economic value of the urban green areas benefits is essential. Several studies exist in which hedonic property value models are used to value various types of urban open spaces such as parks, natural areas and general open spaces. There are also several papers that use hedonic property value models to estimate the value of private green space.

2.4.1 Parks

The earliest studies using housing prices to implicitly value open space focused on parks. Kitchen and Hendon (1967) investigated the housing price effects from the distance to neighbourhood parks in Lubbock, Texas. They calculated a simple correlation between house price and the distance to a neighbourhood park. The authors also calculated correlation between a house's assessed value and its distance to a neighbourhood park. They found a significant positive correlation between house price and distance. Although this result is based only on simple correlations that do not control for the many other factors affecting house values, the result has been confirmed in some other studies looking at urban and suburban parks.

Weicher and Zerbst (1973) investigated the impacts of five neighbourhood parks on single-family dwellings prices in Columbus, Ohio. They used dummy variables for whether a house is adjacent to and faces a park, backs to a park, or is adjacent to and faces an area of heavy recreational use or a park building. They found positive price effects for properties adjacent to and facing a neighbourhood park, other things being constant, but negative price effects if an adjacent property either backs to a park or is across from a heavily used park or park building.

More studies with a broader focus continue to pick up this negative price effect on houses located next to busy urban and suburban parks. King *et al.* (1991) estimated the value of wildlife habitat in an urban/suburban setting using data from the Tucson, Arizona, area from 1986. The explanatory variables included distances to various types of parks and wildlife habitats defined over census blocks with assessed house values as the dependent variable. They found that the farther the houses from busy neighbourhood, district and regional parks, the higher the house prices. Shultz and King (2001) picked up the same price effect using the same types of explanatory variables and focusing on the same city, but from 1990.

By contrast, both the King *et al.* (1991) and the Schultz and King (2001) studies found that the closer the houses are to golf courses, large natural areas and certain types of wildlife habitat, the higher the house prices. The protected areas in the mountains surrounding Tucson were considered as the large natural areas in the studies. The wildlife habitats were defined and spatially located for the purpose of aiding with land use planning in the Tucson area and were delineated only on the basis of habitat and no other factors. There were two types of habitat variables; one was found to be statistically significant in explaining house prices and the other was not. Both of the studies also included a “vacant land” variable defined to include units of land two hectares or larger not classified as wildlife habitat. In both studies, they found that, when all else was equal, house prices increased the farther those houses were from vacant land. In the case of both the “vacant land” variable and the two habitat variables, the type of ownership, private or public, was not classified in the model.

Peiser and Schwann (1993) investigated the price effects from publicly usable open space between houses in a Dallas subdivision, which was referred to as an internal greenbelt by the authors. They found that properties on the open space generally had higher selling prices, but the effect was statistically insignificant and much smaller in magnitude than the effect of the residential land area. An additional square foot of private backyard was estimated to be worth $384 (in 1985 dollars), while an additional square foot of open space was found to be worth less than $4. The results indicated that public open space within subdivisions was not that valuable. The authors stipulate that the results may be specific to the type of subdivision and open space studied. Specifically, their subdivision contained high-end housing with private land areas averaging one-third to one-half acres; the greenway was relatively open and used for jogging, ballgames and with views similar to that of a golf course.

Results in Lutzenhiser and Netusil (2001) confirm the earlier findings about the differential price effects from natural areas and urban parks. Using data on single-family home sales in Portland, Oregon, in 1990–1992, they found that houses near urban parks have lower prices, other things being equal. However, those properties close to natural areas or small parks for a particular use, such as a boat ramp facility, had higher prices. Natural parks had the largest effect on house values and in general, property values increased as the area of the natural park increased. Although the price effect from a neighbouring urban park was negative, the size of an urban park had a positive price effect.

In an earlier study, Bolitzer and Netusil (2000) used the same Portland data as in Lutzenhiser and Netusil (2001) to investigate the effects of open space on house prices. But this time, the authors disaggregate open space in more categories. They categorise open space as public parks and private parks and also include golf courses and cemeteries. According to the authors, the majority of open spaces are public parks and private parks are owned by organizations such as the Trust for Public Land. Public parks and golf courses had positive price effects, but private parks had no statistically significant effects.

Espey *et al.* (2001) focused on a much smaller city, Greenville, South Carolina. The population of Greenville is about a tenth of the population of Portland, Oregon. The authors stated that Greenville is one of the largest and fastest growing metropolitan areas of South Carolina. They attempted to quantify the value of neighbourhood parks, which can be used by city and county planners to plan for future park spaces as the population grows. They found that the value of park proximity vary with respect to park size and types of amenities available such as playground equipment, sporting facilities, walking trails and other amenities. Their estimates from this study were larger than previous studies. The greatest impact on property values was found with proximity to small neighbourhood parks. With the positive impact of proximity to both small and medium-size parks extending to properties as far as 457 meters from the park.

Smith *et al.* (2002) modelled and estimated hedonic price functions to assess whether fixed and adjustable private land uses around residential areas, along with protected public lands, contribute differently to the properties' values. The authors included distance to open space categorized as "fixed" or "adjustable". The fixed open space category included golf courses, publicly accessible open space such as parks and a corridor for a major highway. The adjustable category included agricultural, forested and vacant lands. They were not confident that they could distinguish agricultural and forested lands, therefore they included only vacant lands in the "adjustable" category for most of the regressions.

The Smith *et al.* (2002) sample consisted of house sales between 1980 and 1998 in the Research Triangle area of North Carolina. The authors estimated their model for four separate five-year sub-periods. They included distance to the nearest vacant land, golf course, public lands and lands for the interstate highway, portions of which were built during the sample period. They also included dummy variables for whether the property was on a golf course, public lands, vacant lands, or the land for the interstate. In general, the results suggested that next to or near a golf course were valuable, but no other open space benefit provided value. In fact, being closer to public open space was not valuable. Being closer to the interstate open space corridor was valuable during the 1985–1989 sub-period, not valuable during the 1995–1998 sub-period and had no statistically significant effect during the other two sub-periods. Next to or near vacant land either had no evident effect or had effects that appeared to be at odds with each other.

The authors suggested that their results confirm the problems identified by Irwin and Bockstael (2001) that because many land uses are endogenously determined and because people have different expectations for the future use of some types of open space, it is difficult to capture open space benefits. The authors concluded that "the task of developing an index to represent these amenities is more complex than most of the empirical literature has acknowledged." One of the shortcomings of this paper is that detailed categorisations of land uses are not included in the hedonic model. The vacant land use category and the public land use category are probably too broadly defined in this study. Results from several of studies, namely Schultz and King (2001), Lutzenhiser and Netusil (2001) and in particular Anderson and West (2003), highlight the importance of distinguishing different types of public open space in a hedonic model.

Anderson and West (2003) argued that in hedonic price studies, it is essential to consider jointly the range of open space attributes, such as the open space type, its size and proximity to it. Moreover, the authors argued, open space effects should be quite different depending on the location of residents in a metropolitan area. They used 1997 data from the Minneapolis–St. Paul metropolitan area, twin cities in the state of Minnesota to estimate separate hedonic price models for the city and the suburbs. The explanatory variables included distance and size variables for various types of open space such as developed neighbourhood parks, natural areas, wildlife refuges, state and regional parks, golf courses, cemeteries, lakes and rivers, as well as interaction terms between distance and size for each type of open space. In addition to estimating separate city and suburb models, they also included neighbourhood fixed effects to control for unobserved/omitted housing market variables. Their results indicated that a nearby park of any kind increased property values in the city but had no effect on property values in the suburbs. They also found that the size of parks and open space had no statistically significant effect on house prices in either the city or the suburbs when evaluated at the mean distance and size. However, the interaction terms were quite important. The effect of distance varied depending on the size of the park. House prices increased more with proximity to a larger park.

The Anderson and West study is one of the studies dealing with the wide range of theoretical and empirical issues associated with valuing open space using hedonic price methods. Their market segmentation model, the separation of city and suburbs along with the inclusion of fixed effects, is a good improvement in hedonic property value models for the valuation of open space. The fixed effects help correct for problems associated with omitted/unobserved variables. Particularly, the fixed effects can remedy for spatial autocorrelation and the bias caused by correlation between the omitted variables and the open space variables. Including both distance and size of the open space and the interaction terms are quite useful in exact interpretation of how open space affects values. Unfortunately, the interaction terms make it hard to separate out the individual effects of size and distance and some of the results when evaluated at the mean distances and sizes may provide misleading open space values. On the one hand, at the mean distances to the nearest lake and to the nearest golf course, which is far because of the interaction term, an additional acre of open space of this type appears to lead to a reduction in the house price. On the other hand, it is likely that an additional acre of these amenities is quite valuable for houses close by. Another problem is that the authors were unable to include all types of open space, such as potentially developable land in the model.

Later Anderson and West (2006) used the same technique and the same data set, but allowed the effects of proximity to vary with socio-economic and location variables. These variables included population density, income, crime, percentage of population less than 18 years old and aged 65 years and older, distance to the central business district and private land size. Anderson and West (2006) results had two important insights. First (also achieved in their earlier paper) was that the exclusion on local fixed effects biased estimates for observed characteristics. For instance, when fixed effects were excluded, the sales price of an average house decreased with proximity to a neighbourhood park. Second, the effects of proximity to open space on sale prices varied widely with neighbourhood and location characteristics. Consistent with the Anderson and West (2003) study, the value of proximity to neighbourhood and special parks diminished as distance to the central business district increased. However, the value of proximity to neighbourhood and special parks rose with population density and income. Proximity to neighbourhood parks was more valuable in neighbourhoods with more children, while the benefits of proximity to special parks were higher in neighbourhoods with fewer children. The benefits of proximity to parks were greater in high-crime areas. The benefits of proximity to golf courses also depended on neighbourhood characteristics and location. The amenity value of proximity to golf courses declined as distance to the central business district rose. However, it declined as population density increased and diminished as the fraction of the population age 65 and older increased.

All of the studies above estimated the benefits of open space amenities and did not include any disamenities in their models. Tajima (2003) investigated the economic benefits of proximity to parks and the costs of proximity to highways in the city centre of Boston, Massachusetts, using hedonic pricing approach. Redevelopment of inner Boston, including the relocation of a large highway to create 12 hectares of new open space, provided an opportunity for Tajima (2003) to apply a hedonic model to estimate the benefits of spatial changes.

Assessed values of condominium units in central Boston were used to estimate the implicit prices for their location attributes. These were added to a property database using GIS. The empirical analysis showed that proximity to urban open space had positive impacts on property values, while proximity to highways had negative impacts on housing prices. Therefore, it was expected that the highway demolition and creation of open spaces in central Boston would cause significant increases in the prices of neighbourhood properties.

Tajima studied the price effects of environmental amenities and disamenities, proximity to parks and proximity to highways. In contrast, Morancho (2003) investigated the price effects of environmental amenities not disamenities. Morancho applied the hedonic method to estimate the monetary value of urban green areas in the city of Castellon, Spain. He estimated the hedonic price function in which the housing sale prices were related to dwelling structural characteristics and the environmental variables. The environmental variables included the distance from the nearest urban green area to the house in meters, the size of that urban green area in squared meters and the existence of views of a park or a garden. According to the estimates obtained, only the distance from a green area was significant. He found an inverse relationship between dwelling sale price and distance from a green urban area.

Dehring and Dunse (2006) looked at the housing price effects from proximity to urban parks. They did not investigate the housing price effects from size of urban parks and scenic views as Morancho's study. The authors tested whether large public parks as recreational open space are a substitute for private residential yards. They also tested whether price effects from proximity to urban parks are increasing in housing density. They used a hedonic modelling approach to test the relationship between house prices and proximity to five large city parks for the city of Aberdeen, located in the North East of Scotland. The data included 8,521 sales of three residential property types in the UK, namely detached and non-detached housing and flats within 800 meters of city parks. They showed that the value of park access differs across housing types by density. Their investigation revealed positive and significant price effects from additional proximity to parks for flats, but not for lower density housing types; detached and non-detached housing.

In a study, Kong *et al.* (2007) also implicitly evaluated urban green space amenities in a spatial context using GIS. Kong *et al.* (2007) employed hedonic pricing technique to quantify green space amenities in Jinan, China. According to the authors, no previous hedonic studies exist for the valuation of environmental attributes in China. Kong *et al.* (2007) suggested the reason may be related to the traditional real estate market system for the absence of hedonic pricing studies, upon which it was impossible to access and verify house transaction prices. The residential housing reform, which took place in 1998, resulted in a free housing market with consumers given the right to enter the property market and choose housing attributes depending on their taste. The current real estate market system made it possible to undertake hedonic pricing studies. Kong *et al.* (2007) took an advantage of the current residential welfare system and conducted a hedonic pricing study to indirectly evaluate green space amenities, educational environment and environmental disamenities in Jinan.

Kong *et al.* (2007) selected 124 housing clusters. Sampled properties had similar housing structural characteristics in terms of the building age, interior and exterior design features. The surveyed properties differed mainly with size. Therefore, the real transaction property price per square meter of each housing cluster was chosen to be the dependent variable in their model. Thereby, the property location was the geometrical centre of each housing group and was determined by GIS.

Kong *et al.* (2007) considered three urban green space types; park, plaza and scenery forest in their modelling. They developed size-distance index as the natural log of the ratio of the size of the nearest green space to the distance to the nearest green space. Kong *et al.* included the spatial landscape metrics, which were characterized by differing richness, density, or aggregation, of urban green area and land-use. They also included proxy variables for education environment and the environment disamenity of industrial pollution, location dummies and measures of the ease of accessibility to the central business district and to the three types of urban green area. They used two functional forms for the hedonic price models; linear and semi-log.

Results indicated the positive impact of proximate urban green spaces on house prices. Green space amenity variables that were statistically significant at the 5 per cent level were the size-distance index of scenery forest, accessibility to park and plaza green space types and the percentage of urban green space.

2.4.2 Waterfronts

In urban-rural planning, the socio-economic value of ecological factors needs to be understood and measured. The socio-economic value of ecological factors, green areas and open spaces including water bodies, can be determined through a premium that houses in these desirable settings attract over less favourably located houses. A quantification and specification of this premium may help policy decision makers in urban-rural planning to determine the distribution of green areas, open spaces, water bodies and houses over new urban areas.

In an early study, Brown and Pollakowski (1977) found that publicly accessible open space in lakefront communities in the Seattle area had a positive effect on house prices. The greater the open space around a house, the higher the price, everything else being constant. The authors also found that house prices decreased with distance from the lakefront and were higher when the house had a lake view.

Luttik (2000) studied and measured the value-increasing effect of nearby green spaces, open spaces, water bodies and attractive landscape types on housing prices in The Netherlands. These issues have been addressed in the US and the UK, but less so in The Netherlands. In The Netherlands, urban pressure in some major cities and towns is high. There is also a high demand for green areas and open spaces for recreational purposes. The integrated development of urban and green plans is a relevant policy issue.

In the Luttik (2002) study, a hedonic pricing method was used to derive the value-increasing effect of an attractive setting on house prices. Luttik (2002) used approximately 3000 house transactions in eight towns or regions located in the centre, north and south of The Netherlands. Due to housing market segmentation, house transactions were studied for each research area separately. Data were collected from the Dutch Association of Estate Agents. To control for inflation, the period 1989-1992, which was characterised by price stability, was selected.

Luttik's (2000) analysis was carried out in two stages. A linear regression of house sale prices on structural housing characteristics was estimated in the first stage. It was assumed that the difference between the estimated price and the actual sale price could be related to the difference in location and environmental attributes. The difference between the estimated price and the actual sale price expressed as a percentage of the estimated price was linked to location and environmental variables in a second linear regression analysis. Only the results from the second stage were presented and discussed in the paper.

Luttik's (2000) found that prices for houses with a garden facing a sizeable lake had the largest increases in values of up to 28 per cent. Findings also showed that a pleasant view could lead to a considerable increase in house price, particularly if the house overlooks water bodies, which attracts a premium of 8-10 per cent, or if the house faces an open space, it attracts a premium of 6-12 per cent. The effect of green areas on house prices was indeterminate. In addition, the analysis revealed that house price varies by landscape type. Attractive landscape types were shown to carry a premium of 5-12 per cent over less attractive settings.

Cho *et al.* (2006) estimate the global and local impacts of proximity to water bodies and park amenities on residential property values in Knox County, Tennessee using GIS information in the hedonic pricing function. They adopt a locally weighted regression approach to deal with the nonstationarity and spatial autocorrelation issues.

The natural log of housing sale prices as a function of the structural, neighbourhood and location characteristics was considered as a global model. Cho *et al.* (2006) estimated overall marginal implicit prices of proximities to parks and water bodies with OLS technique using the global model. Cho *et al.* (2006) noted that this marginal implicit price for the nearest park overall is an average across all parks in the study area. Cho *et al.* (2006) then developed a locally weighted regression model to reveal the willingness to pay for increased proximity to any particular individual park or water body. The locally weighted regression assigns non-zero weights to houses nearby a particular park or water body and weights decrease the farther houses are from that park or water body. This explains the nonstationarity relationships between proximity to parks and water bodies and sale prices in the hedonic housing price model. Because the local model allows regression coefficients to vary across space, measuring the spatially varying partial derivative of the local model with respect to any characteristic quantifies the local value of that characteristic individually. Cho *et al.* (2006) calculated the marginal implicit price of proximity to the nearest park by taking the first partial derivative of that specific park in the local model.

The results of Cho *et al.* (2006) indicated the superior performance of the local model over the global framework when incorporating GIS information into hedonic models. The adjusted R-squared was higher and the residual sum of squares was lower in the local model. The estimated marginal implicit price of proximity to local parks was $172 in the global model, however it ranged from -$662 to $840 locally at an individual park level. The estimated marginal implicit price of proximity to water bodies was $491 in the global model, but ranged from -$497 to $6,032 locally for individual water bodies. The local model captured the differences in effects associated with individual parks and water bodies on housing prices. Cho *et al.* (2006) demonstrated suggested the usefulness of the estimated values from locally weighted regression models for policy decision makers.

2.4.3 General Open Spaces and Natural Areas

Open space more generally, as undeveloped land, has been examined for its influence on land value. Cheshire and Sheppard (1995) examined the effects of both privately and publicly owned undeveloped lands on residential property prices in Darlington and Reading, England. They found that there was a positive impact on residential values only when there was a sufficient scarcity of open space in the town as a whole.

Policy decision making to preserve open space is often justified based on the value of the natural amenities associated with the land such as the biodiversity and habitat, or scenic views the environment provides. However, evidence suggests (Cheshire and Sheppard 1995) that open space may more often be valued most for being permanently preserved, not for providing a particular bundle of open space attributes. There are other studies in the literature that investigate the housing price effects of preserved open spaces.

Tyrväinen (1997) suggests that the preservation of forests or trees has often been neglected in construction of housing areas in many countries. Tyrväinen (1997) investigated whether and how non-market environmental and social urban forest benefits were reflected in property values using hedonic pricing method. Tyrväinen (1997) also attempted to find suitable variables for describing green space benefits in hedonic pricing method studies.

Sale prices and property characteristics of 1006 row house apartments in 14 different housing areas of Joensuu, Finland were collected from local tax authorities. The data were collected from 1984 to 1986. The housing markets were relatively stable in these years. All prices were converted to the 1983 price level using quarterly price indexes for row houses.

Typical landscape features of this town include lakes, rivers and forests. Green spaces represent 34 per cent of the town area. Location variables included in the Tyrväinen (1997) study were the distances to the town centre, shops and schools. The relative amount of forested areas in the housing district and distance to the edge of nearest forested area, wooded recreation area, watercourses and beach were included as environmental variables. Location and environmental variables were measured with respect to each specific row house.

The dependent variable modelled by Tyrväinen (1997) was price per square metre. Linear and log-linear hedonic price functions were estimated. The linear model explained 66.4 per cent of the apartment price variations. The apartment characteristics such as number of rooms, age, sauna and roof type were significant and had expected signs. Location variables were significant also. Age and distance to town centre were the strongest explanatory variables for the apartment price. The environmental variables were all significant at the 5% level, except distance to wooded recreation areas, which was significant at the 10% level. The environmental variables had positive impacts on the apartment price except direct distance to the nearest forest park. The negative impact of nearby forest parks on sale prices was due to small variations within the 'distance to nearest forest park' variable. To further investigate the influence of nearby forest parks on property prices, Tyrväinen (1997) suggested including information on age class and species of the forest and the view and the direction of the forest as seen from the house window.

The log-linear model explained 65.9 per cent of the apartment price variations. The results were the same as the linear model except the t-ratios were only slightly improved for distance to watercourses, wooded recreation areas and beach. According to the results of Tyrväinen (1997) study urban forests benefits were capitalized in the property prices. Proximity of watercourses and wooded recreation areas as well as increasing proportion of total forested area in the housing district had a positive impact on apartment sale prices.

Irwin (2002) used the hedonic pricing method to test whether publicly or privately owned open space that is permanently preserved generates significantly different spillover effects on housing prices than public or private developable open space. Irwin (2002) aimed to explore whether preserved open space attracts a premium and whether the various open space amenities associated with different type of land use have different marginal values. In this research, land use types (cropland, pasture and forests), development potential (developable versus preserved) and ownership type (private versus public) were considered.

Irwin (2002) included approximately 56,000 "arms-length", single transactions of owner-occupied residential properties that sold between January 1995 and December 1999. The study area included suburban and exurban counties within a central Maryland region of the Washington, D.C.-Baltimore metropolitan area. The geocoded data were collected from the Maryland Office of Assessment and Taxation.

Irwin's (2002) hedonic residential pricing model was specified as residential sale prices being a function of structural characteristics associated with the house, location and neighbourhood land use variables. Structural characteristics included were house condition, house type (detached or not), number of full baths and half baths, square footage, footprint of the house, age of the building, sale year and land size. Location variables included were distance to major urban centres, distance to major roads and a dummy to take account of aircraft noise.

Six different categories of neighbourhood open space were considered by Irwin (2002). The first category was privately owned cropland, pasturelands and forested lands. The second and the third were privately owned agricultural easements and privately owned conservation areas that are excluded from development, respectively. Non-military open space owned by the federal, state, or county governments was the fifth category. The last category was military open space owned by the federal government. To capture the externality effects of neighbouring development, three additional measures of land use spillovers were included. Low density neighbouring residential land use, medium and high density residential development and commercial or industrial land use. A variable to control for the net effect of all other neighbouring land uses was also included.

Median household income, population density and the percentage of African-American population within the neighbourhood at the block group level were included in the Irwin (2002) study as measures of neighbourhood quality. County dummies were included to control for differences in public services such as public schools.

Problems associated with the estimation of land use spillovers using hedonic pricing models, such as endogeneity and spatial correlation of the neighbourhood land use variables were addressed by Irwin (2002). The potential endogeneity of open space variables arises when a particular type of open space included in the analysis can be converted to a residential use at any point in the future. Spatial error autocorrelation arises if the open space variables are endogenous, therefore they are spatially correlated with the error term. Endogeneity and spatial error autocorrelation bias the open space coefficients.

Endogeneity, spatial heterogeneity and spatial autocorrelation were addressed by Irwin (2002) using an instrumental variables estimation technique. The instruments were a dummy variable indicating the steepness of a parcel's slope, a dummy variable indicating the drainage potential of the soils, a dummy variable indicating the quality of the soils for agriculture and the log of distance from the two urban centres, Washington, D.C. and Baltimore. These instruments were exogenous to the residential housing market and uncorrelated with the error term but correlated with the spatial pattern of open space and development. While the instrumental variables estimation controls for the bias, it does not correct for inefficiency. To control for inefficiency, Irwin (2002) used a random sample of residential sales data in which nearest neighbours were eliminated.

Results from Irwin's (2002) analysis indicate that neighbouring open space significantly influences the residential sale prices and those different types of open space have differing effects. The spillover effects from preserved open space are significantly greater than those associated with developable farmland and forest. In addition, the spillovers from pasture versus cropland are not significantly different from one another, however pasture generates a significantly greater spillover effect on residential house prices than the spillover effect of neighbouring forests.

Irwin's (2002) findings provide some useful insights regarding the demand for open space preservation. The evidence suggest that the public's demand for open space preservation is motivated more by the fact that open space implies no development than by particular features of open space landscapes. The results provide a partial estimate of the total marginal benefits from open space preservation and therefore offer some guidance for the design of open space preservation policies.

Our review of the literature from the 1960's onwards, in which hedonic property value models have been used to investigate the value of open spaces in urban/suburban areas show that there is economic value on open spaces in urban areas. However, estimated values vary widely across studies which in turn create complexity to generalise results from this vast literature on open space valuation. The economic values on open spaces vary widely with the size of the area, the proximity of the open space to residences and the type of open space. What can be drawn from the existing literature is that open space values are case study specific. Policymakers at all levels of government may find it difficult to use the extant literature for assigning a specific dollar value to a particular open space project. We estimate a spatial hedonic pricing model with fixed effects, to produce unbiased and consistent estimates of the value of environmental amenity in Adelaide, South Australia. Such estimates will be important in placing a value on the economic benefits of residential and environmental amenity and provide support to planners and add quantitative values to the public policy debates.

3. The Importance of Amenity in Planning Metropolitan Growth: Estimation of a Spatial Hedonic Price Model

Since the seminal contributions of Whittle (1954), spatial econometric methods, which incorporate the spatial dependence in cross-sectional data into model specification, have been extended by the works of Cliff and Ord (1973), Ord (1975), Griffith (1988), Anselin (1988a), Haining (1990) and Anselin and Hudak (1992). For more than a decade, empirical econometric work has taken into account the potential bias and loss of efficiency that can result when spatial autocorrelation are ignored in the estimation process. Such estimation methods can be found in Anselin (1998a), Basu and Thibodeau (1998), Pace *et al.* (1998), Dubin *et al.* (1999), Gillen *et al.* (2001) and Pace and LeSage (2004).

Spatial econometric methods have been fairly applied in the studies of the valuation of environmental qualities. Recent examples of spatial hedonic models include Kim *et al.* (2003), Beron *et al.* (2004), Brasington and Hite (2005), Anselin and Le Gallo (2006) and Anselin and Lozano-Gracia (2008).

In this chapter, we take an explicit econometric approach to value residential amenities and environmental attributes in the Adelaide metropolitan area and estimate a spatial lag hedonic model with fixed effects. We define the spatial hedonic price model by means of spatial lag and spatial error with fixed effects developed by Lee and Yu (2010). Spatial lag means that the sale price of a house in suburb i is affected by independent variables in suburb i and the neighbouring suburbs subject to a distance decay weight matrix. As a result, Ordinary Least Square (OLS) estimates are biased and inefficient when spatial lag are ignored in the estimation process. Spatial error is indicative of spatially structured omitted variables that if not dealt with would result in inefficiency with OLS estimation method.

The inclusion of the suburb fixed effects is to deal with omitted/unobserved variables that their spatial effects are constant within suburbs. Generally speaking, there are two types of remedies for the bias caused by correlation between the omitted variables and the environmental variables of interest. One is dealt with the spatial error hedonic model where the error term for a house in suburb i is correlated with the error terms for houses in neighbouring suburbs (the error terms are spatially autocorrelated). The other type is dealt with the inclusion of suburb fixed effects where the error term for a house in suburb i is correlated with the error terms for houses within suburb i (the error terms are not spatially autocorrelated). In our model, we allowed for both spatial and non-spatial autocorrelation. However, the robust Lagrange Multiplier-error test statistic indicates that omitted variables have no spillover effects across spatial units of observations (see Section 3.1.4 for more details). Therefore, the suburb fixed effects are included in our model to deal with omitted variables that their spatial effects are constant within suburbs.

3.1 Methodology

3.1.1 Study Area

The focus of our study is the Adelaide metropolitan area. Adelaide is the fifth largest city in Australia and the capital city of the state of South Australia. The population of Adelaide is about 1.1 million. South Australia has a population of about 1.6 million and 70.3 per cent of South Australia's population is located in the Adelaide metropolitan area (ABS 2006 Census). South Australia's total land area is 984,377 square kilometres, while Adelaide takes up a total of 870 square kilometres. The Adelaide metropolitan area is not governed by one local council but consists of 18 Local Government Areas (LGAs) and 354 suburbs.

Adelaide is a product of many different socio-demographic, economic and planning trends over its history. The city has a history of generous open space planning. Governance of public space is devolved to a local level. Early settlement and land development in the metropolitan area has been influenced by the British notion of gardens and public spaces (Hutchings 2007). Social policies around home ownership, post-war immigration and water have also had a role in shaping the urban landscape. The result is a metropolitan area with distinct public amenity spaces such as the extensive Parklands, a 7.6 square kilometres ring of park area which surrounds the Adelaide central business district, Linear Park, a set of bike trails which bisects the Adelaide metropolitan area running the coast to Adelaide (described in more depth in Mugavin 2004), old established leafy suburbs in the southeast and new developed areas on the northern side and the south-west side of the city.

3.1.1.1 Overview of Environmental Amenities across Adelaide

3.1.1.1.1 Open Spaces across Adelaide

One of Colonel Light's legacies is the parklands, a series of reserves approximately 7.2 square kilometres surrounding the city centre of Adelaide, the suburb of North Adelaide and the area between. The River Torrens passes through the Parklands separating the two central urban suburbs. There is some variability in the usage of these areas, ranging from grassy woodlands through to manicured gardens and lawns. There are public playing fields and playgrounds throughout the parklands. Between Adelaide and North Adelaide there is also the Adelaide Oval and Memorial Drive Tennis Centre both of which host international sporting events and have other associated facilities. In the southeast corner there is a horse racing track (used annually in association with a motor sport event, the Clipsal 500). In the northwest corner there are three golf courses and a 18 hole par 3 golf course.

Linear Park, as the name suggests, is a long ribbon of reserves that straddles the River Torrens from the base of the Adelaide hills to the Gulf of St Vincent (Mugavin 2004). Linear Park merges with the Parklands as it passes between Adelaide and North Adelaide. There are a series of bike and walking trails along its entire length and at different locations there are playgrounds and recreational facilities. The level of upkeep varies along the park's length, with some areas consisting of manicured lawns and garden beds and others being maintained as semi natural environments.

Reserves throughout Adelaide typically consist of grassed areas and native and non-native trees. Some reserves are maintained as semi natural environments. Some reserves provide only open space while others have sporting fields, for organised and social sporting activities, or playground equipment. The reserves around Adelaide vary in size from as small as 153 square meters through to 114 hectare. The larger reserves typically have walking and biking trails.

3.1.1.1.2 Water Bodies

Across the Adelaide metropolitan area, there are a number of rivers including the Little Para River, the Torrens River, the Sturt River, the Patawalonga, the Field River and the Onkaparinga, all of which flow intermittently. However, most flow continuously through the winter carrying stormwater to the Gulf. Numerous small creeks also flow intermittently through these urban catchments. These are all highly modified by urbanisation, flood prevention measures and in the case of the Torrens by weirs to create ornamental lakes. Two other significant artificial lakes, a coastal saltwater lake at West Lakes and the stormwater lakes central to the Mawson Lakes housing development, are existed in the Adelaide metropolitan area.

The coast line is an important water feature across the Adelaide metropolitan area with sand beaches and dunes running from Port Adelaide down to the tip of Noarlunga. The coastline is quite sheltered with rare high wave events.

3.1.1.2 Environmental Disamenities across the Adelaide Metropolitan Area

Environmental disamenities considered in this study include fossil fuel generators, alternative generators and general industries. Fossil fuel generating facilities provide electrical generation to the electrical grid covering the Adelaide metropolitan area. Alternative generators are either associated with petroleum refining or cogeneration plants associated with specific industries. There are two electrical generation sites located in close proximity to each other in Adelaide's northwest and alternative generating facilities are located in Adelaide's north and south.

General industries that provide a full range of light to heavy industrial uses and activities that can generate pollution. Light industries include some fabrication and assembly operations, chemical facilities and also industrial scale food production such as bakeries. Heavy industries include more energy intensive manufacturing and may be perceived to produce more pollution than light industries. These include large scale metal fabrication such as motor vehicle manufacturing, glass and soda ash production and cement works. These are located in Adelaide's northwest and north with some exceptions, such as a car manufacturing plant in Adelaide's southern suburbs.

3.1.1.3 Roads and Public Transit Facilities

The public transport system of Adelaide is managed by the Adelaide Metro. An average of 175,123 metro ticket trips are taken in Adelaide each day, involving public bus, tram, train and O-Bahn (express busway) transport. If each traveller uses two tickets in a day, this is just over 8 per cent of the population of the Adelaide metropolitan area. Most of Adelaide's population drives to work in cars, making Adelaide a highly car-dominated city.

Noise and air pollution can be a detracting feature for residential areas in the immediate vicinity of major roads. Adelaide is organised by main roads zoned as arterial roads, highways and collector roads. Commercial zones, which can include retail and wholesale businesses, are often located on main roads.

Good access to public transportation can be an amenity but the immediate proximity can also be associated with the noise and air pollution of diesel engines. Adelaide has a series of interchanges where multiple transit lines intersect. Interchanges are areas of high frequency public transport. There are also augmented levels of bus service along 'Go Zone' bus routes, which are serviced every 15 minutes during weekdays. Normal bus stops are those that have one service every 30 minutes to an hour during weekdays. The train lines of Adelaide extend northeast to Gawler, northwest to Grange and Semaphore, southwest to Brighton and Noarlunga and southeast to Belair. They are mostly used for passenger trains although some freight trains do travel to Gawler, Noarlunga and through Belair on route interstate.

3.1.2 Data Description

3.1.2.1 Real Estate Variables

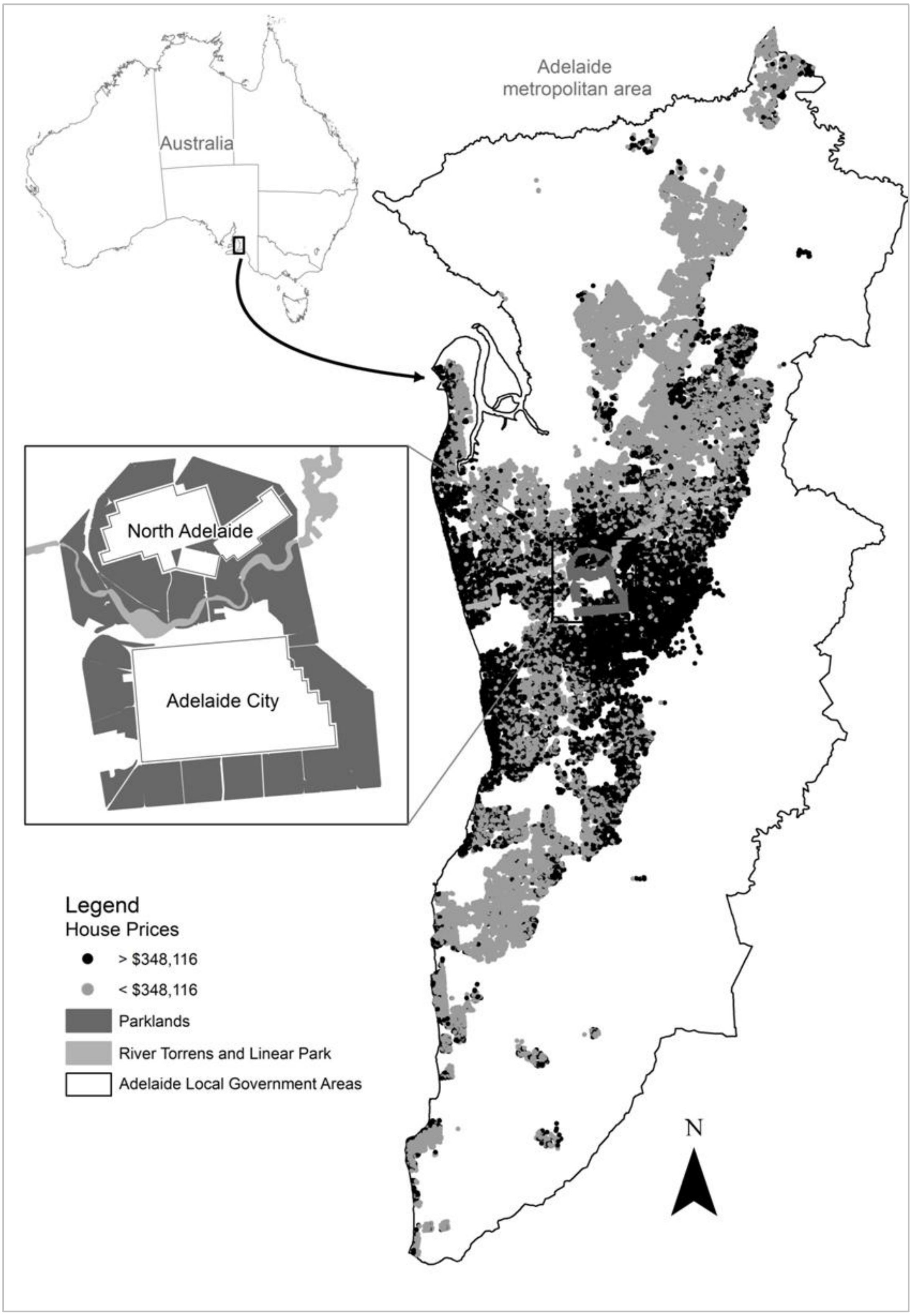
Sales prices and housing attributes for private residential dwellings sold in the Adelaide metropolitan area during January 2005 to June 2008 were collected from a third party, RP Data, specialising in databases of real estate property transactions. RP Data obtain final selling prices from the Valuer-General and augment the basic information with information collected when the property is "on the market".

Key structural attributes considered in this study include total building area, land area, private green area (vegetation area of residential back/front yards), building age (constructed based on its built year), number of bathrooms, number of total rooms, existence of a single or double garage, single or double carport and existence of a swimming pool. Binary variables were constructed for external wall codes and include brick, block, bluestone/slate tile, basket range stone, stone/freestone, iron, rendered and cement sheet/weatherboard/log. Similarly, binary variables were constructed for the roof construction material. These codes included galvanised iron, imitation tile, shingles, tile and other materials.

In addition to the key structural attributes, condition codes were created with six scales of excellent, good, average, fair, poor and very poor. Wall and roof construction, house style and condition codes were rated by the Office of the Valuer-General. The list of real estate datasets and descriptive statistics are given in Table 3.1.

Missing sales prices or implausible observations (non-arms length transactions) and duplicate sales for property data were identified and removed from the dataset. This reduced the size of the estimation sample from 50,668 to 40,923 transactions in 323 suburbs. The spatial distribution of the sales is presented in Figure 3.1.

Figure 3.1 Locations and sale prices of properties over the Adelaide metropolitan area



Note Darker colour dots are properties whose transaction prices are above the sample mean of $348,166 and lighter colour dots are properties with sales prices below the sample mean. The central ring of parklands around the City of Adelaide and the Torrens Linear Park are also depicted in this map.

3.1.2.1.1 Suburb Fixed effects

The suburb fixed effects, 323 suburb binary variables, were included in the spatial hedonic price model. Davoren Park, the suburb with 385 sales and the lowest average selling price of $161,514, was used as the reference. The suburb locations and sale prices of properties over the Adelaide metropolitan area are mapped in Figure 3.1 and Table A1.1 in Appendix 1 lists descriptive statistics of suburb binary variables that were included in the hedonic price model to deal with omitted/unobserved variables that their spatial effects are constant within suburbs.

3.1.2.2 GIS Variables

3.1.2.2.1 Private Green Area

Private green area was mapped using atmospherically corrected, four band multispectral imagery collected with a Vexcel UltraCam digital camera in February 2006 by Aerometrex Pty Ltd. Pre-processing of the image data included shadow removal to prevent dark areas around buildings being miss-classified as vegetation. We removed shadow by applying thresholds to eliminate pixels with low digital numbers in the infrared (75), red (50) and green (50) bands. A normalised difference vegetation index (NDVI) was then applied to classify areas of vegetation within the imagery using the equation:

$$NDVI = \frac{(Infrared - \mathrm{Red})}{(Infrared + \mathrm{Red})} \qquad (3.1)$$

Areas of photosynthetic green vegetation were isolated from other areas of high infrared and red contrast by applying thresholds (0.145 DN) to the NDVI outputs. The thresholds were determined by subjective visual assessment and comparison of aerial photography. An accuracy assessment applied to this classification reported a Kappa of 0.79, indicating 91.21 per cent prediction success using 143 independent validation sites. The amount of private green area within each sold property was then summarised for each residential property. This output was then joined to the data file of house sales.

3.1.2.2.2 Environmental Amenities, Disamenities and Neighbourhood Variables

Table 3.1 lists the datasets and descriptive statistics used in this study to describe amenities and disamenities of the residential environment, as well as neighbourhood variables that are likely to influences house prices. Data were sourced from various local and state government data custodians.

Table 3.1 Variable descriptions and descriptive statistics for the data in the estimation sample

Variable	**Description**	**Median**	**Mean**	**Standard Deviation**	**Min**	**Max**
Dependent Variable						
Price	Private residential dwelling sales price in AU$	$300,000	$348,166	$193,247	$62,000	$3,840,000
Land and House Structural Attributes – General						
Land area	Land size in square metres	682	680	219	68	1904
Green area	Private green space (vegetation area front/back yards) in square metres	240	261	163	0	1880
Building size	Building area in square metres	133	148	53	80	1085
Bath	Number of bathrooms	1	1.38	0.55	1	6
Age	Age of house	33	37	27	0	160
Land and House Structural Attributes – Condition (Coded 1 for listed condition, otherwise 0)						
Excellent	Excellent condition	0	0.03	0.17	0	1
Good	Good condition	1	0.56	0.50	0	1
Average	Average condition	0	0.26	0.44	0	1
Fair	Fair condition	0	0.11	0.31	0	1

Table 3.1 (continued)

Variable	Description	Median	Mean	Standard Deviation	Min	Max
Poor	Poor condition	0	0.04	0.19	0	1
Very poor	Very poor condition	0	0.01	0.08	0	1
Land and House Structural Attributes – Outside Features (Coded 1 if listed feature present, otherwise 0)						
Pool	Swimming pool	0	0.09	0.29	0	1
Carport	Single carport	0	0.37	0.50	0	1
Double carport	Double carport	0	0.25	0.43	0	1
Garage	Single garage	0	0.49	0.50	0	1
Double garage	Double garage	0	0.09	0.28	0	1
Land and House Structural Attributes – Construction (Coded 1 if listed construction present, otherwise 0)						
Mansion	Mansion style house	0	0.00	0.02	0	1
Brick wall	Brick construction	1	0.69	0.46	0	1
Freestone wall	Freestone construction	0	0.08	0.27	0	1
Block wall	Block construction	0	0.02	0.14	0	1
Bluestone wall	Bluestone, slate tile construction	0	0.02	0.14	0	1

Table 3.1 (continued)

Variable	Description	Median	Mean	Standard Deviation	Min	Max
Basket range stone wall	Basket range stone construction	0	0.01	0.10	0	1
Cement wall	Cement sheet, weatherboard or log construction	0	0.04	0.19	0	1
Iron wall	Iron wall construction	0	0.00	0.07	0	1
Rendered wall	Rendered wall construction	0	0.13	0.34	0	1
Galvanised iron roof	galvanised iron roof construction	0	0.25	0.43	0	1
Imitation tile roof	Imitation tile roof construction	0	0.03	0.17	0	1
Shingle roof	Shingle roof construction	0	0.01	0.07	0	1
Tile roof	Tile roof construction	1	0.70	0.46	0	1
Other roof	Corrugated cement sheet, steel decking or slate roof construction	0	0.02	0.12	0	1
Environmental Amenity – Area variable (area of the nearest reserve/national park with listed facilities)						
Area of reserve – garden	No facilities	0.42ha	2.16ha	5.87ha	153m^2	113.94ha
Area of reserve – sport	Sporting facility only or sporting with other facilities	3.65ha	7.21ha	13.28ha	638m^2	83.80ha
Area of national park – hiking	National park with hiking facility only	223.35ha	271.75ha	392.74ha	3,286m^2	1547.96ha
Area of national park – sport	National park with sporting facility only or sporting with other facilities	700.76ha	403.38ha	328.23ha	5.02ha	859.12ha

Table 3.1 (continued)

Variable	Description	Median	Mean	Standard Deviation	Min	Max
Area of waterbodies	Area of nearest lake/wetland/dam	0.27ha	6.88ha	26.12ha	144m^2	27.24ha
Environmental Amenity – Distance variable (distance to nearest reserve with listed facilities)						
Distance to linear park	Distance to the nearest section of linear park	7.90km	10.29km	8.30km	10m	42.17km
Distance to parkland	Distance to the nearest section of the parklands	10.74km	12.29km	8.60km	36m	42.93km
Distance to reserve – garden	No facilities	213m	285.4m	271.62m	1m	3.81km
Distance to reserve – sport	Sporting facility only or sporting with other facilities	488m	576.46m	433.41m	1m	6.10km
Distance to national park – hiking	National park with hiking facility only	4.28km	5.49km	4.23km	10m	19.47km
Distance to national park – sport	National park with sporting facility only or sporting with other facilities	6.29km	7.43km	5.22km	10m	31.47km
Distance to golf course	Golf course	2.44km	2.73km	1.82km	10m	10.70km
Distance to waterbodies	River/lake/creek/wetland	1.27km	1.43km	869.50m	1m	4.40km
Distance to coast	Coast	6.19km	6.75km	4.85km	1m	27.08km
Water Restrictions Level (Coded 1 if listed water restriction level present, otherwise 0)						
Level 3 restrictions	Level 3 water restrictions was introduced on 1 January 2007	0	0.17	0.38	0	1
Tougher level 3 restrictions	Tougher level 3 water restrictions was introduced on 1 July 2007	0	0.25	0.43	0	1

Table 3.1 (continued)

Variable	Description	Median	Mean	Standard Deviation	Min	Max
Environmental Disamenity – Distance variable (distance to the nearest listed disamenity)						
Distance to fossil fuel generator	Fossil fuel generator	9.25km	9.58km	5.34km	291m	32.93km
Distance to alternative generator	Alternative generator	9.25km	10.31km	5.48km	222m	28.46km
Distance to industry	General industries zone	2.01km	2.45km	1.86km	1m	9.96km
Neighbourhood Variable – Distance variable (distance to the nearest listed disamenity)						
Distance to interchange stop	Interchange stop (multiple at least every 15 minutes)	2.83km	3.43km	2.45km	71m	19.42km
Distance to go zone bus stop	Interchange stop (bus available at least every 15 minutes)	525m	993.71m	1.68km	1m	13.75km
Distance to normal bus stop	Interchange stop (bus available every 30 minutes to an hour)	234m	424.91m	975.74m	1m	10.39km
Distance to private school	School that run by private institution	951m	1.09km	657.38m	10m	8.62km
Distance to public school	School that run by the State Government	649m	699.10m	378.97m	40m	6.00km
Distance to train line	Train line	2.62km	3.40km	3.00km	10m	19.63km
Distance to main road	Main arterial road	234m	277.60m	206.90m	1m	1.70km
Distance to commercial zone	Commercial zone	361m	442m	426.48m	1m	6.92km

Table 3.1 (continued)

Variable	Description	Median	Mean	Standard Deviation	Min	Max
Neighbourhood Variable – Census data (census tract level)						
Young	Percentage of population less than 18 years old	23%	23%	5%	0%	41%
Income	Median household income in AU$	$987	$990	$293	$290	$2,639

Note 1 Distances are measured from centroid of each property to the nearest boundary of each variable. All distance and area variables are measured in metres and square metres respectively.

Note 2 Summary statistics are given for variables prior to transformation in any form and based on estimation sample of 40,932 private residential dwellings sold in the Adelaide metropolitan area during January 2005 to June 2008. For simplicity, large numbers are reported in the larger unit.

Each spatial dataset was clipped to a 10 kilometre buffer around the Adelaide metropolitan area defined by the ABS (2006) Census of Population and Housing Adelaide Statistical Division (ASD). Buffering ensures the full influence of location is captured. The environmental amenities we use are all related to public open space, including the Adelaide Parklands and River Torrens Linear Park, reserves and national parks (Figure 3.2). Reserves and national parks were categorized according to the type of facilities available. These facilities include sporting, play equipments and hiking trails. Street directories and inventories of park facilities were used to categorise each reserve and national park. The Euclidean distance to the features within each of the spatial datasets in Table 3.1 was then calculated. The resultant raster surfaces describe, for every location in the study area, the straight line distance in metres to the nearest feature for every 10 metre pixel in the study area. Sizes of reserves and national parks are also measured. The centroids of sold properties were used to allocate the distance of each amenity, disamenity and neighbourhood variable to each property. Spatial distributions of environmental quality and neighbourhood variables are, respectively, presented in Figure 3.2 and Figure 3.3.

Figure 3.2 Location of environmental amenities and dis-amenities in the Adelaide metropolitan area

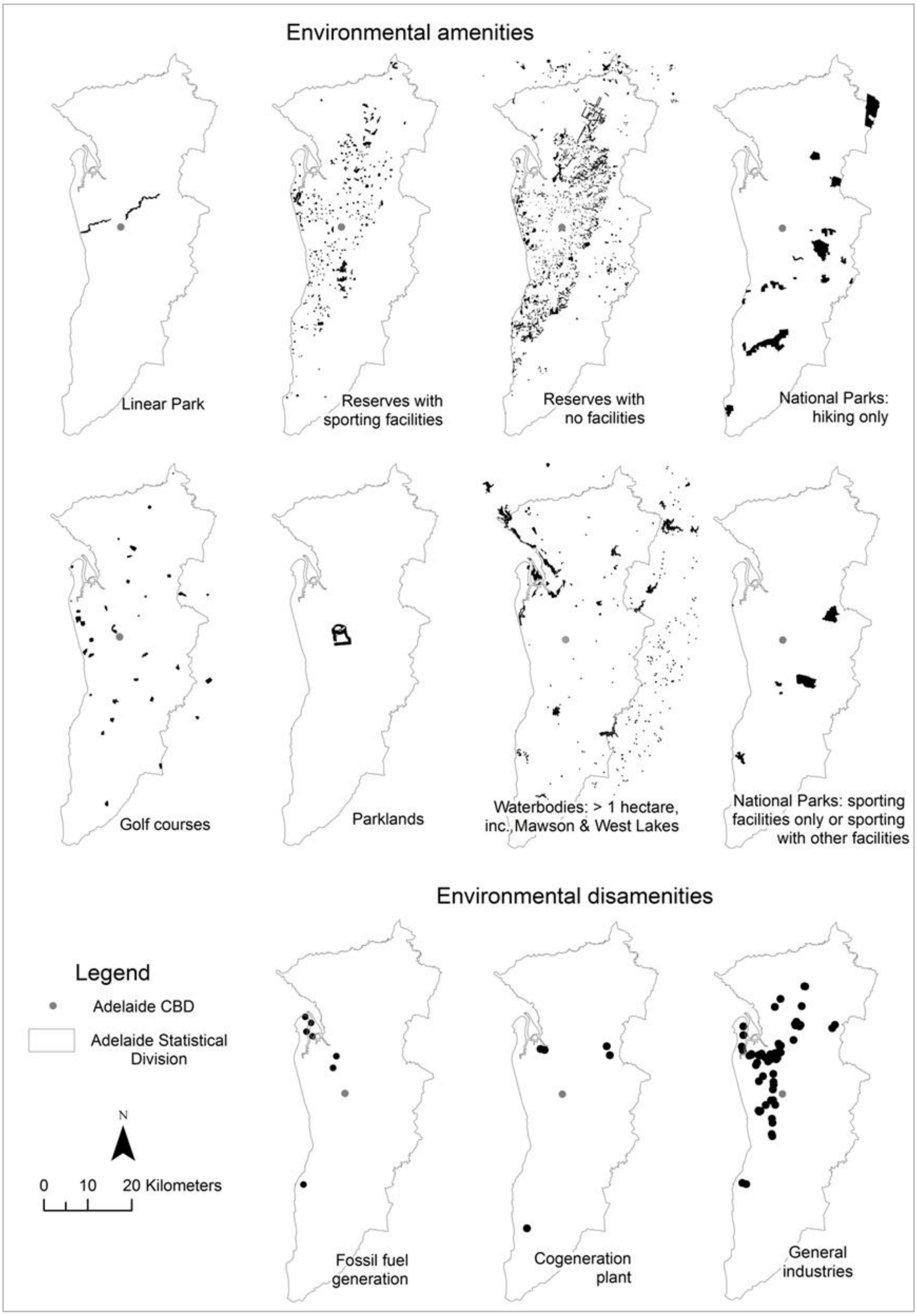
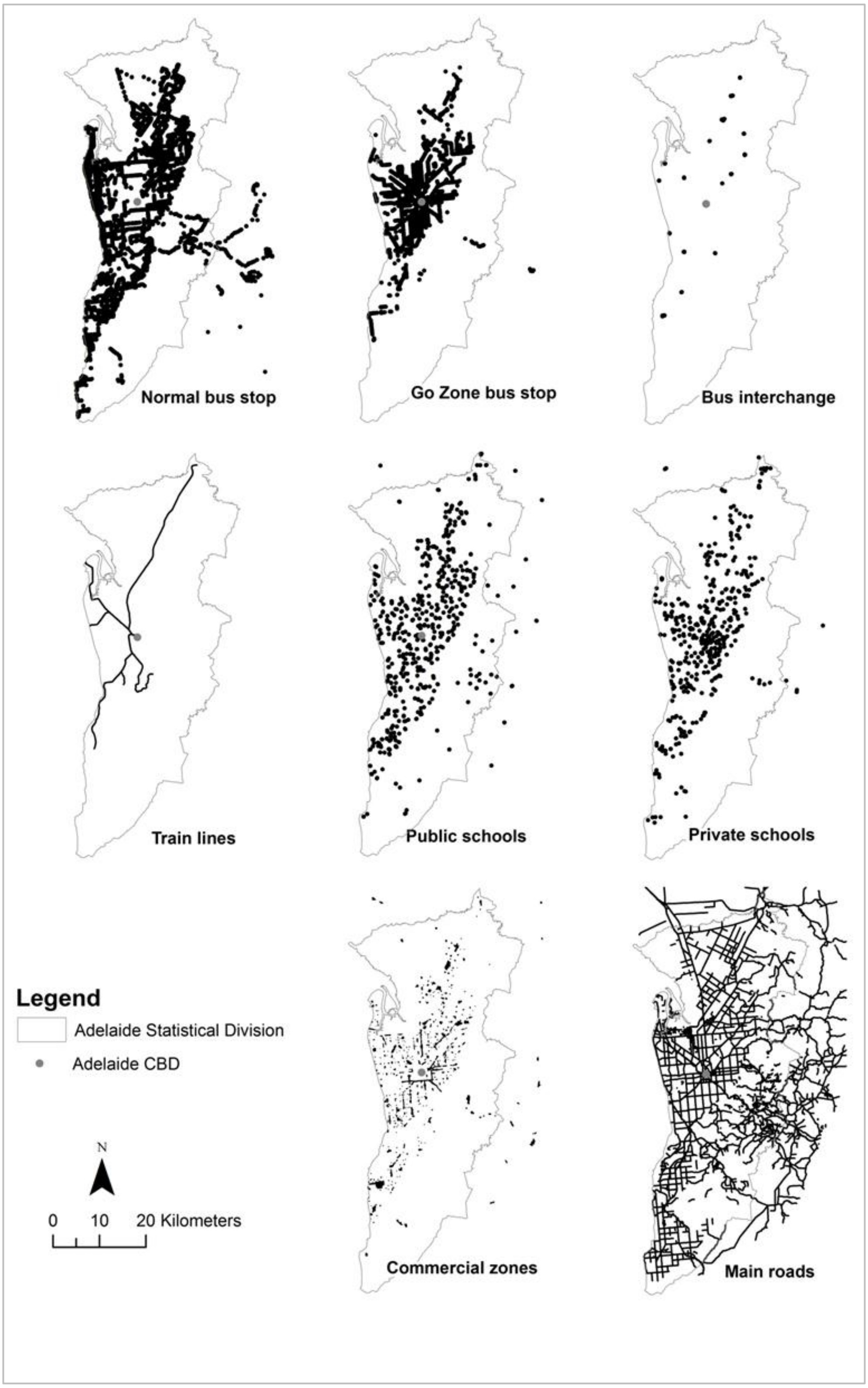


Figure 3.3 Location of neighbourhood variables over the Adelaide metropolitan area



3.1.2.3 Nature of Water Restrictions

The variability of rainfall is now shaping the Australian urban landscape to a much greater extent than in the past. Water for the Adelaide metropolitan area is supplied by the surrounding Mount Lofty Ranges and the River Murray. Significant declines in rainfall across the Murray Darling Basin have lead to historical low levels of inflows to the River Murray over the last decade. While the Millennium Drought has broken, episodic drought and flooding is anticipated to continue with projected regional climatic forecasts suggesting overall less rainfall on average across south-eastern Australia (CSIRO 2008). The South Australian state government has responded to the Millennium Drought and climate projections by introducing infrastructure and policies to reduce demand in the short term but increase supply over the long term. Demand-side policies, such as water restrictions have been implemented and limit the timing of outdoor water use and/or the type of watering system such as sprinklers, drippers, hand held hoses and buckets/watering cans. These sorts of bans impose costs on households by restricting when and how watering takes place to achieve water use reductions (Brennan *et al.* 2007; Grafton and Ward 2008). A desalination plant is currently under construction to increase metropolitan Adelaide's potable water supply (Wittholz *et al.* 2008). New reticulated pipe systems that supply recycled wastewater have been installed for some new urban development sites (Marks 2006). A pipeline system has recently been completed that carries treated wastewater from the Glenelg sewage works to the Adelaide Parklands (Figure 3.1) for surface irrigation.

Table 3.2 describes the scope, timing and levels of water restrictions on watering private outdoor areas and sports grounds and recreation facilities in Adelaide. Water restrictions lower than level 3 are relatively minor restrictions, designed to reduce garden water losses through evaporation. Level 3 and tougher level 3 impose a rigid watering schedule for private outdoor areas. Under tougher level 3 water restrictions, private outdoor areas in the form of lawns cannot be watered at all during the winter and only three hours a week with a trigger spraying device on a hand-held hose during the summer. Use of sprinklers is prohibited in all seasons. However, public sports grounds and recreation facilities can be watered with hand-held hoses on any day between 8pm to 8am, with sprinklers once a week between 8pm and 8am and anytime with watering buckets/cans. The tighter restriction on watering private green areas relative to those on watering sports grounds may lead to a substitution from private outdoor areas to public open spaces.

3.1.2.4 Water Restrictions' Dummy Variables

As water supplies and water policy are important in determining the quality of different public green spaces, a set of binary variables for the introduction of tougher water restrictions were created and then interacted with the public open space variables. The sale dates of properties and the dates on which each level of water restriction came into effect were used to construct the dummies. The merged level 0, 1 and 2 were considered as a base category since these levels of water restrictions are relatively minor. The estimated coefficients of the interaction term between the water restrictions' dummy variable and the public sports grounds variables compare the effects of water restrictions on the value of proximity to public sports grounds and recreation facilities with the base category. The aim is to test if proximity to the public sports grounds and recreation facilities has become more desirable as watering restrictions tighten.

Table 3.2 Scope, levels and timing of water restrictions on watering private outdoor areas and public sports grounds and recreation facilities

NOTE:
This table is included on pages 68-70 of the print copy of the thesis held in the University of Adelaide Library.

Source SA Water

3.1.3 Diagnostic Tests for Spatial Autocorrelation

GeoDa is used to conduct diagnostic tests for trend surface regression models of the dependent variable, the natural logarithm of house prices. Trend surface models are regressions of the dependent variable on the explanatory variables of polynomials in the x and y coordinates of the observations (Anselin 2005). A x coordinate value denotes a location that is relative to a point of reference to the east or west. A y coordinate value denotes a location that is relative to a point of reference to the north or south. A linear trend surface is a regression model in which the explanatory variables consist of x and y coordinates and a quadratic trend surface is a model with x, y, x^2, y^2 and xy as explanatory variables. Both the linear and quadratic trend surface models were estimated for the dependent variable, the natural logarithm of house prices. The regression results indicate that the quadratic trend surface model is a better fit as the adjusted R-squared is higher than the linear trend surface model. All the coefficients in the quadratic trend surface model are significant except the interaction term, xy. The sign of the x coordinate is positive with its square term being negative, suggesting an increasing trend of house prices from West to East with a declining rate. The sign of the y coordinate is negative with its square term being positive, indicating a declining trend of house prices from South to North with an increasing rate.

GeoDa also reports five spatial autocorrelation test statistics, which are computed for the weight matrix of W (the weight matrix characteristics are expressed in Section (3.1.4)). The diagnostic tests for spatial dependence are given in Table 3.3. The first statistic is Moran's *I* of 0.73 with $\text{p-value}=0.00$, which indicates strong spatial autocorrelation problem. The other four test statistics include Lagrange Multiplier-Lag (the standard version of LM test for a missing spatially lagged dependent variable), Lagrange Multiplier-Error (the standard version of LM test for error dependence, followed by the robust versions of the test statistics (Robust LM-Lag and Robust LM-Error). The Robust LM-Lag and Robust LM-Error test statistics are only considered when the standard versions of the test statistics (Lagrange Multiplier-Lag or Lagrange Multiplier-Error) are significant (Anselin 2005).

Table 3.3 Diagnostics for spatial dependence for the 2-nearest neighbour weight matrix (row-standardised weights)

Test	**Moran's *I* / Degree of Freedom**	**Value**	**p-value**
Moran's *I* (error)	0.73	168.08	0.00
Lagrange Multiplier (lag)	1	22025.99	0.00
Robust LM (lag)	1	53.17	0.00
Lagrange Multiplier (error)	1	21973.01	0.00
Robust LM (error)	1	0.18	0.67

Source GeoDa output

The Lagrange Multiplier test statistics are to guide which model specification, spatial lag or spatial error, to use (Anselin 2005). Both LM-Lag and LM-Error statistics are highly significant ($\text{p-value}=0.00$) and therefore we reject the null hypothesis of no spatial lag as well as the null hypothesis of no spatial error. The next step is to consider the robust versions of the test statistics as the null hypothesis by both LM test statistics are rejected. The Robust LM-Lag test statistic is highly significant ($\text{p-value}=0.00$), while the Robust LM-Error test statistic is not ($\text{p-value}=0.67$). The null hypothesis of no spatial lag is rejected, but the null hypothesis of no spatial error cannot be rejected, suggesting a spatial lag specification should be estimated.

3.1.4 Empirical Model and Estimation Technique

The hedonic pricing model is well established and has a long history of use (Rosen 1974). Taylor (2008) provides an overview of equilibrium conditions where a hedonic price function relates the equilibrium market price of a house P_h to its structural and land characteristics S_h, environmental amenity EA_h, environmental disamenity ED_h and neighbourhood attributes N_h:

$$P_h = f(S_h, EA_h, ED_h, N_h) \quad (3.2)$$

A buyer chooses a utility-maximizing house given this price function. The model can be expanded to account for the possibility that the selling prices for properties in close proximity to be related (Samarasinghe and Sharp 2010). The spatial hedonic price model by means of spatial lag and spatial error is expressed as:

$$Y_{n=}\lambda W Y_n + [X_n|Z_n]\begin{bmatrix}\beta \\ c\end{bmatrix} + U_n, \text{ and} \quad (3.3)$$

$$U_n = \rho W U_n + V_n, \qquad n = 1, \ldots, N$$

Where Y_n is the $n \times 1$ vector of the sales price of n houses. The matrix W is $n \times n$ and its elements are non-stochastic distance-based spatial weights. The diagonal elements of W are 0 (self-neighbours are excluded) and the off diagonal elements are non-negative when houses i and j are neighbours, and 0 otherwise. Also, the row sums are 1 a so-called row-standardised weights matrix. GeoDa software was used to construct the k-nearest neighbour weights where $k = 2$ (two neighbours are created for each house). λ is the spatial autoregressive parameter.

X_n is the $n \times m$ factor matrix with the i-th row of X_n gives m factors about the house i. These factors include the house and land structural attributes, its proximity to the nearest environmental amenity, distance from the nearest environmental disamenity and neighbourhood attributes. β is the $m \times 1$ parameter vector will describe the marginal prices of these factors.

Z_n is the $n \times l$ matrix where l is the number of fixed effects, in each row of Z_n there are 2 ones and $l - 2$ zeros. c is the $l \times 1$ parameter will describe the marginal prices of fixed effects. The spatial fixed effects are dummy variables for a suburb at which the house is located. In addition, the quarterly time dummy variables for the time in which the house is sold is included to eliminate the inflation effects on house prices.[5] The inclusion of the suburb dummies in the price function is to deal with omitted variables when their spatial effects are constant within suburbs (McMillen 2010).

Spatial autoregressive disturbances is introduced through U_n. ρ is the spatial autoregressive parameter and $W\ is\ n \times n$ specified spatial weights matrix. V_n is the $n \times 1$ vector of i.i.d. error terms with zero mean and variance σ^2 (Gaussian assumptions).

By defining $S = S(\lambda) = I_n - \lambda W$ and $R = R(\rho) = I_n - \rho W$ and assuming that S and R are invertible, using $U_n = R^{-1}V_n$ the reduced form of the spatial hedonic price model (Equation 3.3) can be rewritten as:

$$Y_n = S^{-1}X_n\beta + S^{-1}R^{-1}V_n \tag{3.4}$$

and re-arranging

$$V_n = R(SY_n - X_n\beta) \tag{3.5}$$

Y_n is normally distributed with a mean of μ_n and variance of Σ, which both defined as:

$\mu_n = S^{-1}X_n\beta$ and $\Sigma = \mathrm{E}[(S^{-1}R^{-1}V_n)(S^{-1}R^{-1}V_n)'] = \sigma^2 S^{-1}R^{-1}(R^{-1})'(S^{-1})'$.

With spatial lag in the hedonic price function, the price of a house in suburb i is affected by the factor variables in suburb i and the neighbouring suburbs subject to the spatial weight matrix of W. Ordinary Least Squares would result in biased and inefficient estimators when spatial lag problem is present. We use the maximum likelihood approach to estimate the spatial hedonic Equation (3.3)

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[5] The quarterly time dummies are interacted with standard variable home loan rates to capture the effect of mortgage interest rates on the housing market.

when $\rho = 0$, as the Robust LM-Error is not significant indicating that omitted variables have no spillover effects across spatial units of observations (residuals are not spatially autocorrelated). The fixed effects are included in the spatial lag hedonic price function to deal with omitted variables that their spatial effects are constant within suburbs.

When $\rho = 0$, the hedonic price function with spatial lag is expressed as:

$$Y_n = \lambda W Y_n + X\beta + V_n \tag{3.6}$$

Where Y_n is the $n \times 1$ vector of the sales price of n houses, X_n is the $n \times m$ factor matrix, W is the $n \times n$ specified spatial weights matrix and V_n is the $n \times 1$ vector of i.i.d. error terms with zero mean and variance σ^2.

Let $\theta = (\beta', \lambda, \sigma^2)$ and $\delta = (\beta', \lambda)$.

The log-likelihood function of:

$l(\theta) = -\frac{n}{2}\log(2\pi\sigma^2) + log|\det(S)| - \frac{1}{2\sigma^2}V'(\delta)V(\delta)$,where

$V(\delta) = Y - X\beta - \lambda WY$

If we are given λ then the maximum likelihood estimator for β is:

$$\hat{\beta}(\lambda) = (X'X)^{-1}X'S(\lambda)Y \tag{3.7}$$

where $S = S(\lambda) = I - \lambda W$ as defined above.

Likewise the maximum likelihood estimator for σ^2 is given by

$$\hat{\sigma}^2(\lambda) = \frac{1}{n}Y'S'MS(\lambda)Y \tag{3.8}$$

where

$$M = I - X(X'X)^{-1}X' \tag{3.9}$$

The concentrated log-likelihood function for λ is then

$$l(\lambda) = -\frac{n}{2}(\log(2\pi) + 1) + log\left|\det\big(S(\lambda)\big)\right| - \frac{n}{2}\log\hat{\sigma}(\lambda) \tag{3.10}$$

We then find $\hat{\lambda}$ to maximise the $l(\lambda)$ and then the maximum likelihood for β and σ^2 are given by the Equations (3.7) and (3.8) with this choice of λ.

3.2 Estimation Results

Models based on Equation (3.2) were systematically estimated by adding structural, land and neighbourhood characteristics as well as environmental quality variables. Initial specifications of the model were estimated in Stata 10 and subjected to a Box-Cox test for functional form and a Ramsey F-test to arrive at the specification involving 65 variables in a double log functional form with respect to the dependent variable and all the distance metrics to the attributes of environmental quality. This formulation of the house, land and neighbourhood characteristics is consistent with the approach in the literature (Cropper *et al.* 1988; Taylor 2003). To make the interpretation of the interaction terms simpler we normalised the covariates prior to estimation using the transformation by Anderson and West (2006):

$$A^* = (A - \bar{A})/\bar{A} \tag{3.11}$$

where, A is the covariate vector prior to normalisation and $\bar{A}$ is their sample median.

Ordinary Least Square (OLS) estimates are potentially biased and inefficient if spatial dependence is ignored in the estimation process. Using GeoDa, a trend surface regression model of the natural logarithm of house prices indicates there is a quadratic trend suggested by the data (Anselin 2005). The sign of the x coordinate is positive with its square term being negative, suggesting an increasing trend of house prices from West to East with a declining rate. The sign of the y coordinate is negative with its square term being positive, indicating a declining trend of house prices from South to North with an increasing rate. Moran's *I* of 0.73 is statistically significant at 1% which indicates strong spatial autocorrelation. Robust Lagrange Multiplier test statistics were used to investigate the existence of either spatial lag or spatial error or both. The Robust LM-Lag test statistic is highly significant ($\text{p-value}=0.00$), while the Robust LM-Error test statistic is not ($\text{p-value}=0.67$)

suggesting a spatial lag specification should be estimated. Fixed effects for suburbs are used to account for omitted variables that have no spillover effects across spatial units of observations.

The estimated coefficients and the marginal impacts for attributes are presented in Table 3.4. The estimated marginal impacts are calculated for a house with median covariate attributes, the reference category for water restrictions and the reference suburb (Davoren Park). Suburbs with few sales were merged with the most comparable adjoining suburbs based on crime statistics and median household income. The estimated implicit prices associated with all of the binary variables are calculated using $\exp\left(\hat{c} - \hat{V}(\hat{c})/2\right) - 1$ where $\hat{c}$, $V(\hat{c})$ are the estimated coefficient and variance for a binary variable, respectively (Halvorsen and Palmquist 1980).

3.2.1 Land and House Structural Attributes

The effects on price associated with standard land and structural variables are as expected, with increased land and house size, as well as more bathrooms having a positive impact on price. An additional square metre of land area is associated with a price increase of $76 (2008 Australian $ used throughout) while controlling for all other characteristics of the house and land that are available. An additional square metre of private green area increases sales price by about $17 for an average sized property. Sales price rises by about $810 for every additional square metre of building area. An additional bathroom raises sales price by about $11,301. Finally, the sale price of the house falls by about $167 for every one year increase in its age. The existence of a swimming pool attracts a premium of $15,295 on average. The estimated marginal prices of a double garage, a double carport, a single garage and a single carport are approximately $8,195, $6,933, $4,382 and $2,984, respectively. This indicates a house with more parking attracts a higher premium.

Table 3.4 Estimation results

Dependent Variable: lnprice	**Coefficient**	**Standard Error**		**Estimated Marginal Impacts (AU$)**
Variables				
Land and House Structural Attributes – General				
Land area	0.00038	0.00002	***	76
Land area ^{2}	0.00000	0.00000	***	-
Land area × green area	0.00006	0.00002	***	-
Building size	0.00331	0.00009	***	810
Building size ^{2}	0.00000	0.00000	***	-
Bath	0.03767	0.00191	***	11,301
Age	-0.01006	0.00030	***	-167
Age ^{2}	0.00019	0.00001	***	-
Age ^{3}	0.00000	0.00000	***	-
Land and House Structural Attributes – Condition				
Excellent	0.07831	0.00586	***	23,492
Good	0.03498	0.00226	***	10,493
Fair	-0.02685	0.00291	***	-8,054
Poor	-0.06185	0.00500	***	-18,554
Very poor	-0.09501	0.01125	***	-28,504
Land and House Structural Attributes – Outside Features				
Pool	0.05099	0.00269	***	15,298
Single garage	0.01461	0.00175	***	4,382
Double garage	0.02732	0.00259	***	8,195
Single carport	0.00995	0.00173	***	2,984
Double carport	0.02311	0.00199	***	6,933

Table 3.4 (continued)

Dependent Variable: lnprice	Coefficient	Standard Error		Estimated Marginal Impacts (AU$)
Land and House Structural Attributes – Construction				
Mansion	0.23197	0.06708	***	69,590
Freestone wall	0.04266	0.00336	***	12,798
Block wall	-0.01197	0.00516	**	-3,590
Bluestone wall	0.03928	0.00569	***	11,783
Basket range wall	0.02394	0.00638	***	7,182
Cement wall	-0.05015	0.00499	***	-15,045
Iron wall	-0.08005	0.01375	***	-24,016
Rendered wall	0.01501	0.00246	***	4,503
Imitation tile roof	-0.01881	0.00509	***	-5,642
Shingles roof	-0.03355	0.01044	***	-10,066
Tile roof	0.00682	0.00214	***	2,047
Other roof	0.00659	0.00744		1,975
Environmental Amenity				
ln (Distance to linear park)	-0.00923	0.00298	***	-0.35
ln (Distance to parkland)	-0.05555	0.00655	***	-1.55
Distance to road × ln (Distance to parkland)	-0.00170	0.00022	***	-
ln (Distance to reserve – garden)	0.00092	0.00086		1.29
Area of reserve – garden × ln (Distance to reserve – garden)	-0.00005	0.00001	***	-
ln (Distance to reserve – sport)	-0.00257	0.00117	**	-1.58
Area of reserve – sport × ln (Distance to reserve – sport)	0.00005	0.00005		-
ln (Distance to reserve – sport) × Level 3 restrictions	0.00331	0.00217		-
ln (Distance to reserve – sport) × Tougher level 3 restrictions	-0.00366	0.00181	**	-
ln (Distance to national park – hiking)	0.00606	0.00225	***	0.42

Table 3.4 (continued)

Dependent Variable: lnprice	Coefficient	Standard Error		Estimated Marginal Impacts (AU$)
Area of national park – hiking × ln (Distance to national park – hiking)	0.00018	0.00008		-
ln (Distance to national park – sport)	0.02613	0.00325	***	1.25
Area of national park – sport × ln (Distance to national park – sport)	0.00106	0.00059	*	-
ln (Distance to national park – sport) × Level 3 restrictions	-0.00615	0.00224	***	-
ln (Distance to national park – sport) × Tougher level 3 restrictions	-0.01152	0.00202	***	-
ln (Distance to golf)	-0.00439	0.00187	**	-0.54
ln (Distance to water bodies)	-0.00184	0.00155		-0.43
Area of wbodies × ln (Distance to water bodies)	0.00001	0.00002		-
ln (Distance to coast)	-0.10281	0.00383	***	-4.99
Environmental Disamenity				
ln (Distance to fossil fuel generator)	0.04761	0.00586	***	1.54
ln (Distance to alternative generator)	0.02639	0.00520	***	0.86
ln (Distance to industry)	0.02235	0.00142	***	3.34
Neighbourhood Attributes				
ln (Distance to interchange stop)	-0.00733	0.00275	***	-0.78
ln (Distance to go zone bus stop)	0.00036	0.00125		0.20
ln (Distance to normal bus stop)	0.00195	0.00109	*	2.49
ln (Distance to private school)	0.00045	0.00152		0.14
Young × ln (Distance to private school)	-0.00918	0.00402	**	-
Income × ln (Distance to private school)	-0.00028	0.00361		-
ln (Distance to public school)	0.00554	0.00142	***	2.56
Young × ln (Distance to public school)	0.00279	0.00432		-
Income × ln (Distance to public school)	0.01470	0.00384	**	-
ln (Distance to train line)	0.00971	0.00178	***	1.11

Table 3.4 (continued)

Dependent Variable: lnprice	**Coefficient**	**Standard Error**		**Estimated Marginal Impacts (AU$)**
ln (Distance to main road)	0.02044	0.00200	***	26.21
ln (Distance to commercial zone)	0.00413	0.00098	***	3.43
Fixed Effects				
Interest rate	-0.00340	0.00726		-1,021
Quarter property sold × Interest rate	Significant *** except 1st * and 2nd quarters 2005 **			
Suburb fixed effects	Significant *** except Noarlunga Downs and Smithfield			
Constant	10.088	0.130	***	-
Spatial autoregressive parameter (λ)	0.102		***	
R-squared	0.899			
No. of observations	40,923			

*** indicates that the estimated coefficient is significant at α =1%, ** α =5% and * α =10%.

3.2.2 Environmental Amenities

The impact of open spaces across the Adelaide metropolitan area has a series of estimated effects (Table 3.4). A negative coefficient for distance metrics indicates that the selling price is increasing as the distance from the feature decreases. The estimated coefficient on proximity to the nearest segment of Linear Park is negative and significant at $\alpha = 1\%$ indicating that price increases by $350 for a property one kilometre closer, noting that this is calculated at the median for all continuous variables. The impact of the historic multi-use Adelaide Parklands is more complicated. The Parklands surround the central business district. The Parklands in turn are surrounded by main roads. The normalised proximity to the nearest main road is interacted with proximity to Parklands to distinguish between the price effects of the Parklands and main roads. Overall, the price increases by about $1,550 for every kilometre closer the property is to the nearest part of the Parkland. The estimated coefficient is significant at $\alpha = 1\%$.

Proximity to the nearest reserve with no facilities is positive but not significant (Table 3.4). However, the interaction term between proximity to a reserve without any facilities and its size is negative and significant at $\alpha = 5\%$. The distance to a national park with hiking trails interacted with park size is positive and significant at $\alpha = 1\%$. This suggests that national parks with hiking facility are not regarded as amenities. National parks with trails for walking may detract from the final selling price because they remain in a natural, unmanaged state throughout the year. There is also a heightened fire danger and pestilence risk associated with national parks. Thus households may choose to drive to these areas rather than live nearby. Proximity to the nearest reserve with sporting facilities is negative and significant at $\alpha = 5\%$. For every 100 metre closer the property is to this feature raises sales price by about $158 (Table 3.4). The estimated coefficient on the interaction term between distance to the nearest reserve with sporting facility and its size is positive and not significant. This suggests that above average sized sport fields have no positive price effects.

With water restrictions, there is potential for households to substitute between private green space and sporting ovals as ovals are generally well-watered and maintained open spaces. To test for evidence of substitution, proximity to the nearest reserve or national park with a sporting facility (which are watered more regularly) is interacted with a binary variable for the water restriction levels. This interaction term is negative and significant (at $\alpha = 5\%$) at the tougher Level 3 water restrictions. This suggests that some substitution may be occurring.[6] At the tougher Level 3, the marginal price for proximity to the nearest reserve with sporting facility rises by about $380 per 100 meters closer for an averaged size reserve. The effect is not quite the same with the distance to national parks with sporting facilities interacted with park size. This interaction is positive and significant at $\alpha = 10\%$. However, the estimated coefficients on national parks with sporting facilities become negative and significant at $\alpha = 1\%$ with the introduction of Level 3 and tougher Level 3 water restrictions.

The estimated coefficients for distances to golf courses and the coast are negative and significant at $\alpha = 5\%$ and $\alpha = 1\%$ respectively (Table 3.4). The sales price increases by about $540 for every kilometre closer a property is to a golf course. Proximity to Adelaide's sandy beaches add $4,990 for every kilometre closer the property is to the beach. The estimated coefficient for distances to a waterbody is negative but not significant.

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[6] We run the model without suburb fixed effects, to check the sensitivity of the coefficients of proximity to the nearest reserve or national park with a sporting facility at level 3 and tougher level 3 water restrictions (Table A2.1 in Appendix 2). The results indicate the robustness of the estimated coefficients.

3.2.3 Environmental Disamenities

All the estimated coefficients for distances from the environmental disamenities are positive and significant at $\alpha = 1\%$ (Table 3.4). Property value decreases by $1,540, $860 and $3,340, respectively, for every kilometre closer the property is to the nearest fossil fuel generator, alternative fuel generator and general industrial zone.

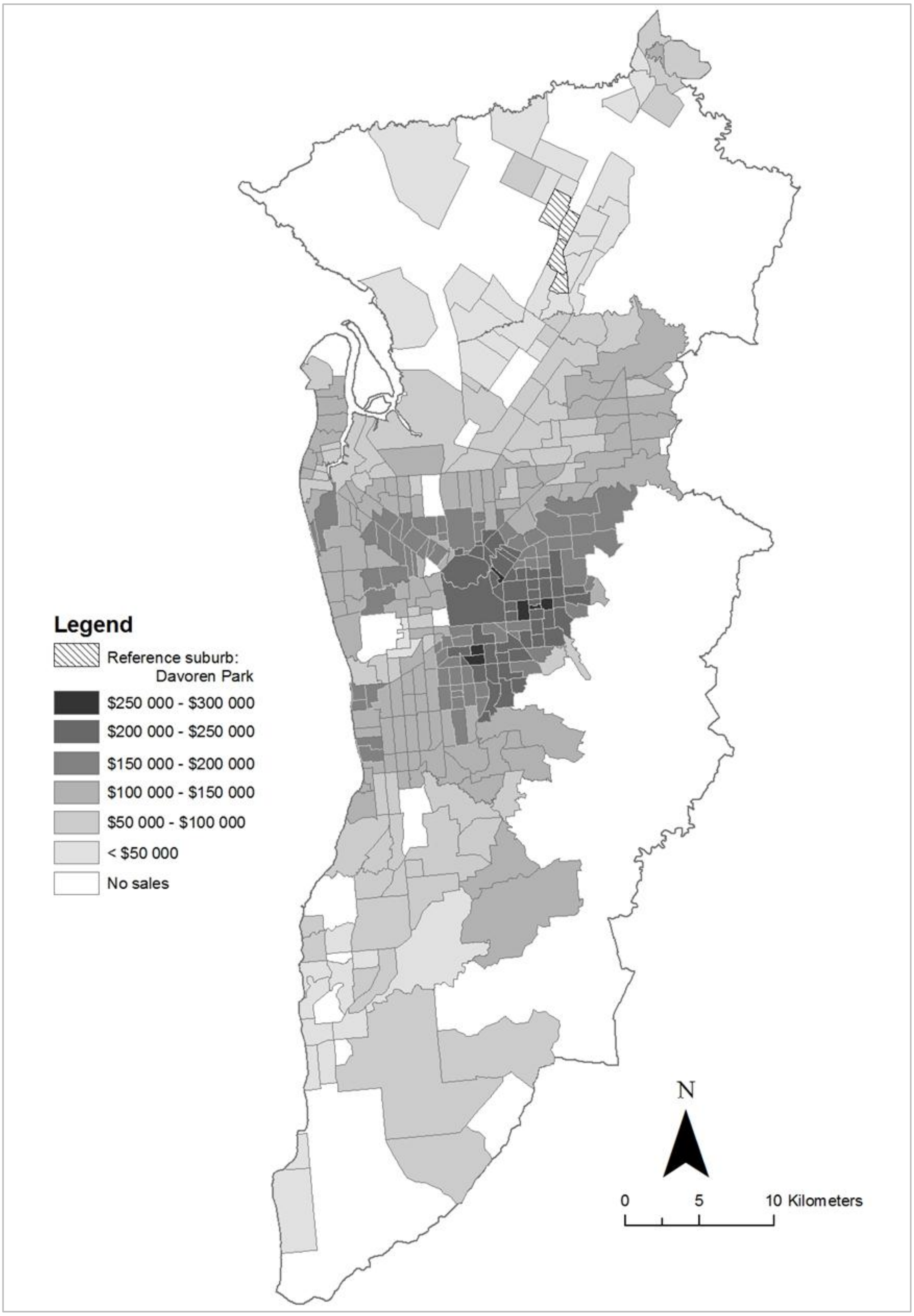
3.2.4 Neighbourhood Variables

Many of the proximity metrics for public transportation were positive and not significant (Go Zone bus stops with higher frequency bus schedules) or were positive but significant at $\alpha = 10\%$ indicating a detracting quality to the attribute (normal bus stops or train lines; Table 3.4). Adelaide is a car-dominated city with less than 5 per cent of employed people using public bus transport to get to work. Proximity to the nearest private and public school were also estimated. Private schools are an amenity in the areas where the percentage of population less than 18 years old is higher. Public schools across the Adelaide metropolitan area are not an amenity as the coefficient for proximity to the nearest public school is positive and significant at $\alpha = 1\%$.

3.2.5 Suburb Fixed Effects

A series of fixed effects were used to capture any remaining neighbourhood characteristics for which there is presently limited data. Davoren Park, the suburb with the lowest median selling price, was used as the reference. The residual value that might be attributed to each suburb was calculated and mapped in Figure 3.4. A strong geographic clustering of higher valued suburbs is situated around the parklands and the base of the Adelaide Hills. These suburbs have traditionally commanded a premium over and above all the characteristics of the house, land and environmental quality of the surrounding area.

Figure 3.4 Map of fixed effects over the Adelaide metropolitan area



4. The Effects of Environmental, Social and Economic Amenities on Economic Development in Rural Australia: Estimation of a Spatial Simultaneous System of Equations

4.1 Literature Review

Early regional economic studies largely disregarded the possible effects of location-specific environmental amenities on economic growth. However, the 1970s' location specific population growth patterns in the U.S. generated significant interests among economists to investigate the impacts of location-specific environmental amenities on regional economic development (Greenwood 1985; Deller *et al.* 2001).

Waltert and Schläpfer (2010), in their review paper, provided an overview on the impacts of location-specific environmental amenities on economic growth in addition to the importance of amenities relative to other economic factors (where lagged economic dependent variables included in the analysis). They analysed 25 empirical studies that reported estimates of amenity impacts on three dependent variables of population, employment and income. Their conclusion was that areas with higher natural and environmental amenities attract more population, but the amenity effects on employment growth are limited, while the impact on income growth remains uncertain. Moreover, Waltert and Schläpfer (2010) concluded that high employment growth significantly promoted population change.

In the literature, system-of-equations models are often employed to model the impacts of environmental amenities and other exogenous socio-economic variables on multiple dependent variables such as population, employment and income change (Chun 1996; Duffy-Deno 1997b, 1998; Anjomani 2002; Lewis *et al.* 2002; 2003; McGranahan and Wojan 2007; McGranahan 2008).

Traditionally, these types of models have been used to investigate empirically whether people follow jobs or jobs follow people (Steinnes and Fisher 1974; Carlino and Mills 1987). Early contributions to this line of research used regional dummies or climate variables and costal dummies as proxies for location-specific amenities (Graves 1980; Carlino and Mills 1987; Clark and Murphy 1996). In the 1990s empirical researchers have shown an increasing interest to explore the role of a wide range of specific measures of natural and environmental amenities on regional development. The range of environmental amenities considered in the literature and also used in our analysis includes forests, wetlands, natural preserve areas and agricultural lands (Gottlieb 1995; Deller *et al.* 2001; Green 2001; Marcouiller and Clendenning 2005; Waltert and Schläpfer 2010).

An influential methodical advance was the development of spatial econometric techniques which were first applied to a regional growth model by Boarnet (1994) and subsequently used in studies on effects of amenities on regional change (Gottlieb 1995; Lewis *et al.* 2002; 2003; Boarnet *et al.* 2005; Kim *et al.* 2005; Nzaku and Bukenya 2005; Ali *et al.* 2007; Ferguson *et al.* 2007; McGranahan 2008; Partridge *et al.* 2008; Wu and Mishra 2008; Gebremariam *et al.* 2009; Deller 2010).

Overall, the available regional economic studies indicate that regions with higher environmental amenities tended to grow faster in terms of population than other regions. However, the evidence on the dependencies between environmental amenities and employment or income remains unclear. As identified in the extensive Waltert and Schläpfer (2010) review, there is a need for empirical regional economic system-of-equations studies with a broad range of specific amenity measures to support the role of environmental amenities in regional economic development. Furthermore, the focus of the majority empirical studies in the literature is within the United States. A better understanding of the role of environmental amenities in regional economic development in other countries is an important objective to which empirical research can contribute. To the best of my knowledge, the only study that examined the role of environmental amenities in regional economic development in Australia is the Tapsuwan *et al.* (2011) research.[7] They examined the spatial dependencies between environmental amenities and overall economic growth in terms of population, employment and income in the MDB. However, the Tapsuwan *et al.* (2011) study was not able to relate population, employment and median income change to several measures of environmental amenity including proximity to forests and lakes and average annual rainfall. These variables had no significant impact on population, employment and median income change. They suggested further investigation and stated that it is too early yet to conclude that environmental amenities in the MDB region have little or no influence on regional communities.

This study provides the estimates of the effects of environmental amenities including forests, major perennial rivers and lakes and natural parks on the percentage changes in population, employment and median income of 153 local government areas (LGAs) in the MDB. As it is demonstrated in the remaining of this chapter, several measures of environmental amenities found to enhance economic development in the MDB. The improvement in the research is due to a better selection of instruments for the endogenous dependent variables.

This study can provide a tool to the Australian government agencies to develop effective policies to promote rural economic development as well as contributing to the existing international literature.

[7] I am the second author of this working paper which is not included in this thesis.

4.2 Specification and Implication of the Model

In this study, we apply the spatial simultaneous equations model developed by Kelejian and Prucha (2004) which is the extension of the widely used spatial single equation model introduced by Cliff and Ord (1973; 1981). More specifically, the following system of m spatially interrelated cross sectional equations corresponding to n cross sectional observations is considered as:

$$Y_n = Y_n B + \bar{Y}_n \Lambda + X_n \Omega + U_n \tag{4.1}$$

where

$Y_n = y_{jn} = (y_{1n}, \dots, y_{mn}),$

$\bar{Y}_n = (\bar{y}_{1n}, \dots, \bar{y}_{mn}),$

$\bar{y}_{jn} = W y_{jn},$

$X_n = x_{ln} = (x_{1n}, \dots, x_{kn}),$

$U_n = u_{jn} = (u_{1n}, \dots, u_{mn}),$

$j = 1, \dots, m$ and $l = 1, \dots, k$

y_{jn} is the $n \times 1$ vector of the endogenous variables in the jth equation where n is the cross sectional units, $\bar{y}_{jn}$ is the spatial lag of y_{jn}, W is the $n \times n$ spatial weights matrix, x_{ln} is the $n \times 1$ vector of cross sectional observations on the exogenous variable l where $l = 1, \dots, k$, u_{jn} is the $n \times 1$ vector of the error terms in equation j and B, Λ and Ω are, respectively, the $m \times m$, $m \times m$, and $k \times m$ parameter matrices. Λ is specified as a non diagonal autoregressive parameter matrix and therefore the endogenous variable in the jth equation depends on its own spatial lag as well as the spatial lags of other endogenous variables in this simultaneous equations context.

The existence of the spatial lag term Wy_{jn} in the model will induce a nonzero correlation with the error term, irrespective of the correlation structure of the errors. Furthermore, the spatial lag of the endogenous variable, $\{Wy_{ji}: i = 1, \dots, n, j = 1, \dots, m\}$, is not only correlated with the error term at location i, but also with the error terms at all other locations. Thus, the nonzero covariance is in the form of $E\left[(Wy_{ji})u_{jn}\right] = E[\{W\left(I - \lambda_j W\right)^{-1} u_{jn}\}u_{jn}] = \sigma^2 \left[\left(I - \lambda_j W\right)'(I - \lambda_j W)\right]^{-1}$. The resulting nonzero covariance matrix implies that each location is correlated with every other location but diminishing in magnitude with the powers of W in the series expansion of $\left(I - \lambda_j W\right)^{-1} = I + \lambda_j W + \lambda_j W^2 + \lambda_j W^3 + \cdots$. OLS estimates would result in biased and inconsistent estimators when the spatial lag of endogenous variable is ignored in the model specification (Anselin and Bera 1998). An instrumental variable (IV) method is suggested for the estimation of the simultaneous equations with the spatially lagged endogenous variables (Anselin 1980; 1988a; 1990b). Since the main issue, is the correlation between the spatial lags of the endogenous variables and the error terms, the proper selection of instruments for the spatially lagged endogenous variables will lead to consistent estimates. It is demonstrated that the IV estimates are consistent in the spatial lag model with first order and higher-order spatially lagged exogenous variables (WX_n, W^2X_n) as instruments (Kelejian and Robinson 1993; Kelejian and Prucha 1998).

The spatial autocorrelation in the error terms are also considered in the model in addition to general spatial lags in the endogenous variables. In particular, the error terms are determined by the first-order autoregressive process as follows:

$$U_n = \overline{U}_n R + E_n \tag{4.2}$$

where

$E_n = (\varepsilon_{1n}, \dots, \varepsilon_{mn})$,

$R = diag_{j=1}^{m}(\rho_j)$,

$\bar{U}_n = (\bar{u}_{1n}, \dots, \bar{u}_{mn})$,

$\bar{u}_{jn} = W u_{jn}$

ρ_j is the unique spatial autoregressive parameter in the jth equation for the error lag Wu_{jn}. R is a diagonal matrix and therefore the vector error terms in equation j only to its own spatial lag. The spatial autoregressive error process is multivariate normal with zero mean and a nonzero error covariance matrix of $E[u_{jn}u'_{jn}] = \sigma^2 \left[(I - \rho_j W)'(I - \rho_j W)\right]^{-1}$. The nonzero error covariance leads to inefficient, while still unbiased, OLS estimates.

The error terms entering the spatial autoregressive process are spatially uncorrelated. However as for the simultaneous equations model, the error terms corresponding to same cross sectional unit are allowed to be correlated across equations. ε_{jn} is the $n \times 1$ vector of the error terms in the jth equation and assumed to be i.i.d. with $E\varepsilon_{jn} = 0$ and $E\varepsilon_{jn}\varepsilon'_{kn} = \sigma_{jk} I_n$.

The *j*th equation in (4.1) and (4.2) can be rewritten as:

$y_{jn} = Z_{jn}\delta_j + u_{jn}$, and (4.3)

$u_{jn} = \rho_j W u_{jn} + \varepsilon_{jn}$

where

$Z_{jn} = (Y_{jn}, X_{jn}, \bar{Y}_{jn})$ is the matrix of observations of right hand side variables in equation j and $\delta_j = (\beta'_j, \gamma'_j, \lambda'_j)$ is the corresponding parameter vector.

Since $u_{jn} = (I - \rho_j W)^{-1}\varepsilon_{jn}$ and thus $y_{jn} = Z_{jn}\delta_j + (I - \rho_j W)^{-1}\varepsilon_{jn}$, multiplying both sides by $(I - \rho_j W)$, equation (4.3) can be rewritten as:

$$y^*_{jn}(\rho_j) = Z^*_{jn}(\rho_j)\delta_j + \varepsilon_{jn} \tag{4.4}$$

where

$$y^*_{jn}(\rho_j) = y_{jn} - \rho_j W y_{jn},$$

$$Z^*_{jn}(\rho_j) = Z_{jn} - \rho_j W Z_{jn}$$

Stacking the equations yields the equations system as:

$$y^*_n(\rho) = Z^*_n(\rho)\delta + \varepsilon_n \tag{4.5}$$

where

$$\rho = (\rho_1, \dots, \rho_m)',$$

$$\delta = (\delta'_1, \dots, \delta'_m)',$$

$\varepsilon_n = (\varepsilon'_{1n}, \dots, \varepsilon'_{mn})'$, ε_n.is i.i.d. with $E\varepsilon_n = 0$ and $E\varepsilon_n\varepsilon'_n = \sigma_{jk}I_n$.

4.3 Methodology

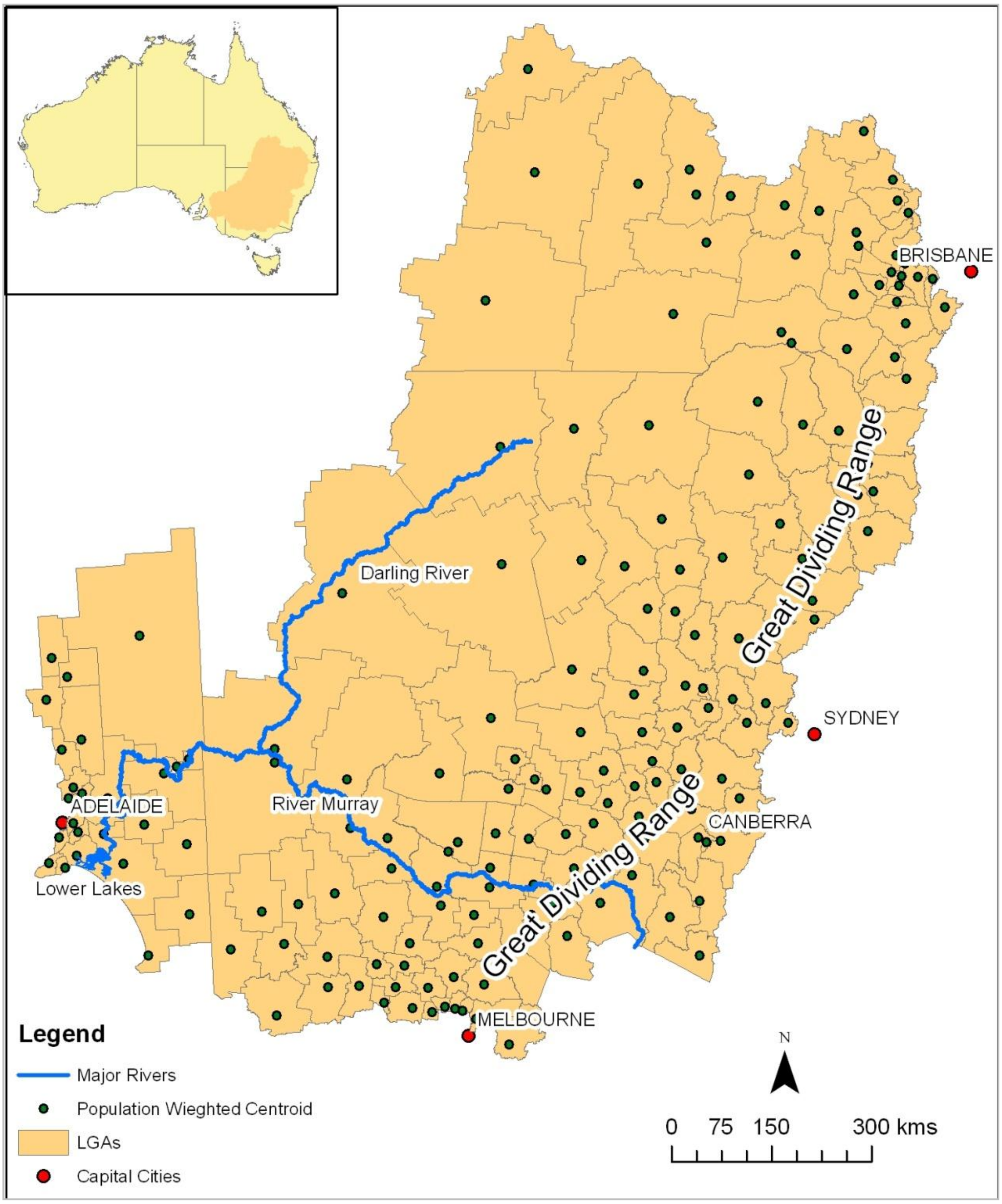
4.3.1 Study Area

This study focuses on the MDB covering an area of one million square kilometres in the interior of the south eastern Australia (Figure 4.1). The Basin accounts for one-seventh of the national land mass and contains important natural resources and significant landscape for agriculture and recreation. Its climates consist of semi-arid highly ephemeral floodplains in the northern regions, cool temperate rainforests in the north east, hot dry arid plains in the west and vast semi arid open woodland plains in the south of the basin.

The basin consists of over 3,700 kilometres of watercourses including Australia's three largest rivers, the Murray River, the Darling River and the Murrumbidgee River. The iconic Murray River runs from the high alpine, reaches in the south-eastern snowy mountains through to the end of the basin where it drains into the southern ocean via the Ramsar-listed lower Lakes Alexandrina and Albert and the iconic Coorong wetlands in SA. The Darling River which is fed by tributaries in the sub-tropical northern part of the basin and cool warm eastern highlands runs down the dry arid western plains where it drains into the Murray River just east of the South Australian border. The Murrumbidgee River flows from the high alpine country of the Snowy Mountains running largely east-west until it also drain into the Murray River downstream of Narrung.

The region contains 9.4 million hectares of national parks and reserves including 17 Ramsar-listed wetlands such as the Coorong, Lakes Alexandrina and Albert, Barmah and Gunbower forests and the Macquarie Marshes. It is bordered by the Great Dividing Range along its eastern watershed where most of the runoff is generated.

Figure 4.1 Map of the study area



Economically the region is dominated by agricultural production with both irrigated and non-irrigated activities occurring throughout the basin. The MDB agriculture accounts for 34 per cent of Australia's gross value of agricultural production (Bryan and Marvanek 2004). Over 75 per cent of irrigated agriculture occurs within the basin and this accounts for 36 per cent of the profit generated in the MDB. While agriculture occurs in just less than 90 million hectares, half the profits are generated from under 1 million hectares (Bryan and Marvanek 2004). Dryland cereals and sheep or cattle grazing dominate the landscape covering over 95 per cent of all agricultural area. Horticultural activities provide the greatest returns to agriculture in the region despite only consuming less than 5 per cent of the total agricultural area.

Demographically over 2 million people, 10 per cent of the Australian population, live in the MBD and 10 per cent of the residents in the MDB are employed as farmers which represent 38 per cent of all Australia's farming community (ABS 2006). The Basin's population grew by 3 per cent from 2001 to 2006 census (our study period). The vast majority of the population resides along the western side of the Great Dividing Range and along the course of the River Murray.

The basin is covered by a complex set of governing bodies with varying degrees of authority, responsibilities and geographical extents from federal government to state, local and catchment management authorities as well as the Murray Darling Basin Authority. For the purposes of this study Local Government Areas (LGAs) have been chosen as the spatial unit. The LGA represents the smallest geographically defined regions that are a democratically elected governing body with legislative powers. These governing bodies are largely responsible for the direct care and maintenance of recreational facilities and natural environment in their district (LGA). A total of 153 LGAs are in this study comprising 33 LGAs from Queensland, 21 LGAs from South Australia, 28 LGAs from Victoria and 71 LGAs from New South Wales.

4.3.2 Data Description

All the data used for this study were geographically constrained to the Local Government Areas (the spatial units) which were subsequently constrained to the MDB study area boundary. The MDB catchment area was buffered by 100 kilometres to ensure any potential amenities that exist just outside the boundary were included in the analysis.

4.3.2.1 Economic and Social Data

A number of economic and social variables of the study area were collected from the 2001 and 2006 Census of Population and Housing.[8] The Census of Population and Housing is conducted by Australian Bureau of Statistics (ABS) every five years. It is the most detailed and comprehensive collection of statistical information on population, employment, median income and a variety of other economic and social attributes. The results of the Census are available to public at a range of various geographic and statistical levels such as LGA.

The endogenous economic and social variables used in this study include the percentage change in population, the percentage change in employment and the percentage change in median weekly household income from 2001 to 2006 in LGA i. There exist spatial and temporal variations in the endogenous economic and social variables across the MDB over the study period, 2001–2006. Over the period of 2001–2006, the LGA of Alpine in Vic experienced population decline of 33 per cent and employment decline of 39 per cent whereas the LGA of Yass Valley in NSW experienced population growth of 35 per cent and employment growth of 40 per cent. The median weekly

[8] All economic and social data in this study is by place of usual residence.

household income in the LGA of Upper Lachlan in NSW declined by 6 per cent while the employment in the LGA of Chinchilla in QLD increased by 62 per cent over 2001–2006.

The exogenous economic and social variables include the population and employment densities per square kilometres in 2001, the median weekly household income in 2001, the population with a college degree in 2001, the population of homeowners in 2001 and the indigenous population for each LGA. The list of economic and social variables and descriptive statistics is presented in Table 4.1.

Table 4.1 Variable descriptions, descriptive statistics and data sources for the data in the estimation sample

Variable	Description	Data Source	Mean	Standard Deviation	Min	Max
Endogenous Variable						
Population change	Percentage change in population in LGA i, 2001-2006	Australian Bureau of Statistics 2001 and 2006 Census at Local Government Area level, Basic Community Profile, CDATA 2001 and 2006, CD-ROM, 2nd release, ABS, Canberra.	0.2%	9.6%	-32.6%	35.3%
Employment change	Percentage change in employment in LGA i, 2001-2006		2.8%	12.0%	-38.8%	39.9%
Income change	Percentage change in median weekly household income in LGA i, 2001-2006		22.9%	10.7%	-5.7%	61.8%
Exogenous Variable						
Environmental Amenity						
Distance to forest	The nearest forest in LGA i, 2001	Geoscience Australia, GEODATA TOPO 250K Series 3, Commonwealth of Australia	23,117m	19,407m	517m	124,853m
Distance to river	The nearest major perennial river in LGA i, 2001		54,504m	69,018m	67m	405,478m
Distance to lake	The nearest major perennial lake in LGA i, 2001		103,001m	75,084m	4,451m	368,403m
Distance to national park	The nearest national park in LGA i, 2001		21,648m	19,237m	140m	124,871m
Crop area	Area of cropland in LGA i, 2001		62,778ha	91,930ha	0ha	564,998ha
Pasture area	Area of pastureland in LGA i, 2001		457,319ha	834,040ha	0ha	5,130,080ha

Table 4.1 (continued)

Variable	Description	Data Source	Mean	Standard Deviation	Min	Max
Climate Attributes						
Rainfall	Average annual rainfall in LGA i, 2001	The Australian Government Bureau of Meteorology	603mm	207mm	251mm	1,356mm
Temperature	Average annual temperature in LGA i, 2001		16^{o}C	2^{o}C	10^{o}C	20^{o}C
Infrastructure Amenity						
Distance to airport	The nearest airport in LGA i, 2001	Geoscience Australia, GEODATA TOPO 250K Series 3, Commonwealth of Australia	44,868m	37,734m	346m	204,795m
Distance to railway station	The nearest railway station in LGA i, 2001		14,966m	19,947m	173m	104,888m
Economic and Social Attributes						
Population density in 2001	Population density per square kilometres in LGA i, 2001	Australian Bureau of Statistics 2001 Census at Local Government Area level, Basic Community Profile, CDATA 2001, CD-ROM, 2nd release, ABS, Canberra.	11	47	0	433
Employment density in 2001	Employment density per square kilometres in LGA i, 2001		0	1	0	11
Median weekly income in 2001	Median weekly household income in LGA i, 2001		AU$627	AU$102	AU$450	AU$900
College graduate in 2001	Population with a college degree in LGA i, 2001		431	433	25	2,493
Home ownership in 2001	Population of homeowners in LGA i, 2001		2,551	2,155	128	13,604
Indigenous population in 2001	Indigenous population in LGA i, 2001		324	492	9	3,399

Note 1 Distances were measured from the population weighted centroid of the LGA to the nearest entry point of the environmental and infrastructure amenities via the road network. Note 2 The estimation sample size is 153 LGAs.

4.3.2.2 Environmental Amenities

For the purposes of spatial analysis in this study, environmental amenity areas have been defined as areas that exist in their natural form or closely resemble a natural feature in the landscape and can be considered to provide some degree of amenity value. Spatial data of environmental amenity areas was obtained from the Geoscience Australia 250k topographic mapping and amenities were then defined and assessed within the spatial units through GIS. To improve clarity some of the environmental amenity areas were reclassified into more descriptive classes such that particular aspects of the amenity type could be identified. For instance, all water related amenity areas were reclassed to distinguish between permanent water presence and irregular water presence (ephemeral). Environmental amenity attributes used in this study include forests, major perennial rivers, major perennial lakes and natural parks (Table 4.1).

Distance metrics were created to identify a travel distance from an origin to a destination via a specified network. An origin – destination (OD) network analysis method within GIS was used for this purpose. The OD network analysis uses points representing origins and destinations and a geometric network of features in the landscape that describe the connectivity between the points. The population weighted centroid of each LGA was defined as the origin. The nearest entry point of environmental amenity areas was defined as the destination rather than geographic centre of each environmental amenity area. Across the Murray-Darling Basin a number of the amenity areas are vast in size and or length. Creating the destination point locations at the geographic centre of each environmental amenity area leads to potentially inaccurate distance calculations. Amenity areas with disproportionately large area relative to the study area force significant travel distance within the parcel to reach the centroid. The class 1 and 2 roads features (highway and major roads) from the Geoscience Australia 250k topographical maps were used to build a road network that connects the origin to destination points.

Agricultural development areas such as cropland and pastureland areas were also included in this study. These agricultural development areas were collected from Geoscience Australia 250k topographic mapping. Table 4.1 describes the environmental amenity variables and descriptive statistics.

4.3.2.3 Climate Attributes

The bioclimatic analysis and prediction system, BIOCLIM, was used to create surfaces characterising the spatial distribution of mean annual rainfall and temperature across the MDB.[9] The rainfall and temperature data were collected from the Australian Government Bureau of Meteorology (BOM). Average annual rainfall and temperature for each LGA were then calculated through Zonal Statistics Tool within GIS.

4.3.2.4 Infrastructure Amenities

A number of other spatially attributable assets in the landscape such as airports and railway stations were also included in the analysis. These additional variables were incorporated to isolate environmental amenity from other sources of amenity value. Infrastructure amenities including airports and railway stations were collected from Geoscience Australia 250k topographical maps. The OD network analysis method within GIS was then used to define the travel distance from the population weighted centroid of each LGA to the nearest infrastructure amenities via roads network.

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[9] Detailed descriptions of BIOCLIM are provided in the works of Nix (1986) and Busby (1991).

4.3.3 Empirical Model and Estimation Approach

Based on the spatial model (Equations (4.1) and (4.2)) developed by Kelejian and Prucha (2004), this study specifies a system of three spatially interrelated equations corresponding to 153 cross sectional observations (Equation (4.6) in scalar notation). This spatial simultaneous system of equations was used to examine the impacts of the initial states of environmental, climate, infrastructure and economic and social amenities in 2001 census on percentage changes in population, employment and median household income from 2001 to 2006 census in the Murray Darling Basin region of Australia. The system of three spatially interrelated equations was specified as:

$$y_{1i,01-06} = \beta_1 y_{2i,01-06} + \beta_2 y_{3i,01-06} + \lambda_j \sum_{j=1}^{m=3} w y_{ji,01-06} + \sum_{l=1}^{k} x_{li01}\omega_j + u_{1i}, \qquad (4.6)$$

$$y_{2i,01-06} = \beta_1 y_{1i,01-06} + \beta_2 y_{3i,01-06} + \lambda_j \sum_{j=1}^{m=3} w y_{ji,01-06} + \sum_{l=1}^{k} x_{li01}\omega_j + u_{2i},$$

$$y_{3i,01-06} = \beta_1 y_{1i,01-06} + \beta_2 y_{2i,01-06} + \lambda_j \sum_{j=1}^{m=3} w y_{ji,01-06} + \sum_{l=1}^{k} x_{li01}\omega_j + u_{3i}, \text{ and}$$

$$u_{ji} = \rho_j \sum_{j=1}^{m=3} w u_{ji} + \varepsilon_{ji}, \text{ where}$$

$$j = 1, \dots, m\ (m = 3),\ i = 1, \dots, n\ \ (n = 153) \text{ and } l = 1, \dots, k$$

The endogenous variables in the model include $y_{ji,01-06}$ and $Wy_{ji,01-06}$. The $n \times 1$ vectors of $y_{1i,01-06}$, $y_{2i,01-06}$ and $y_{3i,01-06}$ measure, respectively, the percentage changes in population, employment and median household income between 2001 and 2006 census in LGA i. $Wy_{1i,01-06}$, $Wy_{2i,01-06}$ and $Wy_{3i,01-06}$ are, respectively, the spatial lags of percentage changes in population, employment and median household income from 2001 to 2006 census in LGA i.

The exogenous variables in the model are denoted by the $n \times k$ matrix of x_{li01}. It is consisted of the initial state of the environmental, climate, infrastructure and economic and social amenities in 2001 census. The environmental amenities include distances from the population weighted centroid of each LGA to the nearest entry point of the nearest forest, major perennial river, major perennial lake and national park via the road network. The area of croplands and pasturelands in each LGA were also included as environmental amenity variables. The climate attributes include average annual rainfall and temperature in LGA i. Distances from the population weighted centroid of each LGA to the nearest airport and railway station in LGA i were considered as the infrastructure amenities. The economic and social attributes are population and employment densities per square kilometres, median weekly household income, population of college graduates and homeowners and indigenous population in each LGA. A detailed description of the variables, descriptive statistics and the data sources are given in Table 4.1.

u_{1i}, u_{2i} and u_{3i} are the $n \times 1$ vectors of the error terms. β_1 and β_2 are scalar regression parameters, λ_j and ρ_j are scalar autoregressive parameters and ω_j is the $k \times 1$ vectors of regression parameters in each equation. ε_{ji} is the $n \times 1$ vectors of the error terms in each of the first-order autoregressive equations and assumed to be i.i.d. with $E\varepsilon_{ji} = 0$ and $E\varepsilon_{ji}\varepsilon'_{ki} = \sigma_{jk}I$.

Stata 10 was used to construct the spatial weights matrix W for two nearest neighbours d for each observation i. We row-standardised the spatial weights matrix so the elements of W:

$$w_{id} = \begin{cases} (1/\sum_{d=1}^{2}|w_{id}|)w_{id}, & \text{if } i \text{ and } d \text{ are neighbours} \\ 0 & \text{otherwise} \end{cases}$$

The row normalised weights matrix has the advantage of using relative distance rather than absolute distance by assigning the matrix elements to a range of 0 to 1. Observations in close proximity were given a relatively greater weight, with the spatial interaction diminishing fast as distance increases.

The Moran's *I* test statistics in Stata supported significant spatial dependency at $\alpha = 1\%$ for two nearest neighbours for $y_{1i,01-06}$, $y_{2i,01-06}$ and $y_{3i,01-06}$, the percentage changes in population, employment and median household income between 2001 and 2006 census in LGA i (Table 4.2). In general, when spatial lag of a dependent variable is present in a dataset, but ignored in a model specification, the resulting specification error is of the omitted variable type and OLS estimates will be biased and inconsistent (Anselin and Bera 1998). Ramsey Regression Equation Specification Error Test (RESET) is a general test for the specification error of the omitted variable type among other types of specification errors (Ramsey 1969).[10] The null hypothesis of no omitted variables was rejected for the OLS estimation of each equation of the percentage changes in population, employment and median household income where the spatial lags of the endogenous variables were ignored at the 1 or 5 per cent level of significance (Table 4.2). Therefore, the RESET along with the Moran's *I* test statistics suggest that the spatially lagged endogenous variables should be included in each equation.

The simultaneous system of the equations of the percentage changes in population, employment and median household income from 2001 to 2006 census in LGA i were estimated using the four-step generalised spatial three-stage least squares (GS3SLS) developed by Kelejian and Prucha (2004). This estimator takes into account the spatial lags of the endogenous variables and the spatial lags of the error terms as well as the cross-equation correlation of the error terms and will lead to unbiased and consistent estimates.

[10] The other types of specification errors include incorrect functional form and correlation between explanatory variables and the error term, which may be caused by measurement error in explanatory variables, simultaneity, or the existence of lagged dependent variable and serially correlated error terms.

In the first step, the parameters, β_1, β_2 , λ_j and ω_j, in the regression model in Equation (4.6) were estimated by applying two-stage least squares (2SLS) and instrumental variable (IV) approaches to each equation. We selected the first and second-order spatial lag of all the exogenous variables (Wx_{li01}, W^2x_{li01}) as instruments for the endogenous variables $y_{ji,01-06}$ and $Wy_{ji,01-06}$. This selection of the instruments is consistent with the approach in the literature (Kelejian and Robinson 1993; Kelejian and Prucha 1998; Wu and Mishra 2008). Sargan test (1958) was used to check for over-identifying restrictions in our model. The Sargan test is based on the observation that the residuals of the IV estimation should be uncorrelated with the set of exogenous variables if the instruments are truly exogenous. A statistically significant Sargan test statistic rejects the null hypothesis of 'the error term is uncorrelated with the instruments' therefore the instruments are not valid. With our data, the null hypothesis of 'the residuals of the IV estimation is uncorrelated with the instruments' could not be rejected suggesting that the instruments were truly exogenous therefore valid (Table 4.2).

In the second step, the spatial lags of the error terms, ρ_j, were estimated in terms of the residuals obtained via the first step of the generalised moments approach developed in Kelejian and Prucha (1999). In our study, none of the spatial lags of the error terms were significant suggesting that there was no spatial autocorrelation in the error terms (Table 4.2). Hence, the third step of the GS3SLS approach to account for spatial autocorrelation in the error terms was not performed in our analysis.[11] Breusch-Pagan test (1979) was used to test for a null hypothesis of homoscedasticity

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[11] The third step of the GS3SLS is the re-estimation of the transformed model using GS2SLS. One can obtain the transformed model via transforming the data using the matrix, $I - \tilde{\rho}_j$ where $\tilde{\rho}_j$ is the estimator of ρ_j from the second step.

against the alternative of heteroscedasticity of the error terms, u_{ji}. The null hypothesis could not be rejected at $\alpha = 1\%$ therefore the error terms were not heteroscedastic (Table 4.2).

In the final step, the GS3SLS estimator for β_1, β_2 , λ_j and ω_j was calculated from stacking the regression equations in Equation (4.6). The estimated parameters are presented in Table 4.2.

4.4 Estimation Results

The estimation results are discussed separately for each equation and presented in Table 4.2. Overall, the models perform well, with 88 per cent of the variations in population change and employment change and 85 per cent of the variation in median income change were explained by the estimated equations. The results indicate that the percentage changes in population, employment and median income over time were affected by a series of factors.

4.4.1 Population Change Equation

Estimates for the equation of the percentage change in population indicate that population growth in LGA i is significant at $\alpha = 1\%$ and positively impacted by employment growth. This result suggests that local government areas with more employment had larger percentage increases in population from 2001 to 2006 census. The significant and positive relationship between population and employment growth is consistent with the Hailu and Brown (2007) study in Austin, Texas.

The spatial autoregressive parameters for population, employment and median income growth are not significant, which suggest population growth between 2001 and 2006 census in an LGA was not influenced by population, employment and median income growth in neighbouring LGAs.

The distance to the nearest major perennial river variable is negative and significant at the 5 per cent level, while the estimated coefficients on distance to the nearest forest and major perennial lake are positive and significant at $\alpha = 5\%$ and $\alpha = 1\%$ respectively. As stated in Section 4.3.2.2, distance variables were measured from the population weighted centroid of the LGA to the nearest entry point of the environmental and infrastructure amenities via the road network. The negative estimated coefficient on proximity to the nearest major perennial river variable suggests that densely populated areas closer to rivers had higher level of population increases. The positive effects of proximity to the nearest forest and lake on the population growth suggest that increase in population growth occurred more in densely populated areas that were further away from forests and lakes.

The estimated coefficients on pasture area and average annual rainfall are negative and significant at $\alpha = 10\%$ and $\alpha = 1\%$ respectively. These results suggest that densely populated areas with smaller pasture areas and lower rainfalls had higher level of population increases.

None of the initial conditions of the infrastructure and socio-economic amenities variables are significant in the population change equation. Hence, the change in population in 2006 census was independent of proximity to airports and railway stations, the level of population density, number of college graduates, number of homeowners and number of indigenous population in 2001 census.

4.4.2 Employment Change Equation

Estimates for the employment change equation indicate that population growth in LGA i is positively impacted by population growth at the 1 per cent level of significance, but negatively impacted by median income growth at the 5 per cent level of significance. The expected positive sign for the population growth variable indicates that LGAs with more population growth provided more employment opportunities. This result is consistent with Garnett and Lewis (2002) who stated that some rural areas in Australia have been experiencing increases in both population and employment. Hailu and Brown (2007) and Wu and Mishra (2008) also found that employment growth is significantly higher in regions with more rapid population increases. The negative relationship between employment growth and median income change is perhaps picking up the different effects of full-time and part-time employments for males and females on median income change at the suburban and rural locations. Part-time employment increased strongly over time in agriculture sector, an important source of employment in regional and rural Australia (Garnett and Lewis 2002). The agriculture industry in rural Australia experienced a substantial change in full-time employment for males and females from 2002 to 2006 (Garnett and Lewis 2002; ABS 1301.0 – Year Book Australia 2008). Full-time male employment declined by 12 per cent, while female employment on a full-time basis experienced a substantial growth by 61 percent between 2002 and 2006. Furthermore, a male-female income disparity existed in Australia where the average annual full-time male wage was proportionally higher than the average annual full-time female wage (ABS 2006 census). The reduction in full-time employment for males, the growth in part-time employment and full-time employment for females together with the male-female income disparity is the possible explanation for the negative relationship between employment and median income growth.

The distance to the nearest forest and major perennial lake are negative and significant at $\alpha = 10\%$ and $\alpha = 5\%$ respectively, while the estimated coefficient on proximity to the nearest major perennial river variable is positive and significant at the 1 per cent level. The negative estimated coefficients on distance to the nearest forest and major perennial lake variables suggest that densely populated areas closer to forests and lakes experienced higher level of employment increases. The positive effect of proximity to the nearest river on the employment growth suggests that rapid employment growth occurred more in densely populated areas that were further away from rivers.

The estimated coefficient on average annual rainfall is positive and significant at $\alpha = 1\%$. This result indicates that densely populated areas with more rainfalls experienced higher level of employment increases.

Similar to the population change model, neither the spatial autoregressive parameters for population, employment and median income growth nor the initial conditions in the infrastructure and socio-economic amenities variables are significant in this equation.

4.4.3 Median Income Change Equation

The endogenous population variable is positive and significant at the 10 per cent level in the median income change model, while employment change is negative at the significance level of 10 per cent. These relationships are consistent with the population change and employment change models.

All the spatial autoregressive parameters for population, employment and median income growth are significant at the 1 per cent level in this model. However, employment change is negative while population and median income change are positive. The negative relationship between the spatial lag of employment change and median income change indicates that an increase in the median income level of an LGA is influenced by the reduction in employment of neighbouring LGAs. The spatial autoregressive parameter for population change is positive and significant, which suggests median income growth in an LGA was positively influenced by population growth in neighbouring LGAs. The positive relationship between the median income change and its spatial lag indicates that the increase in median income of an LGA was influenced by the increase in the median income of neighbouring LGAs. This suggests that wage increase happens in clusters of LGAs.

Similar to the population and employment growth equations, none of the infrastructure amenities variables are significant in the median income change equation. However, two initial conditions of the dependent socio-economic variables, the median income and the population of college graduates, are significant at the 5 per cent level or better in the median income change model. The negative estimated coefficient on 2001 median income indicates that LGAs with higher median income in 2001 experienced slower income growth from 2001 to 2006 census. This result is consistent with Wu and Mishra (2008) and Wu and Gopinath (2008) study in the United States. Wu and Mishra (2008) and Wu and Gopinath (2008) argured that negative relationship between median income in 2001 and median income growth that the model is picking up low demand for labour at the suburban and rural locations where the labour costs are high. This spatial inequality in income appears to also be the case in the MDB. The population of college graduates in 2001 also played a significant role in explaining median income change from 2001 to 2006 census. The positive estimated coefficient on 2001 population of college graduates suggests that higher college graduates tended to lead to higher median income growth in 2006.

The distance to the nearest major perennial river variable is positive and significant at the 1 per cent level. This result is consistent with the employment growth equation. The positive effects of proximity to the nearest major perennial river on the median income growth suggest that increase in median income growth occurred more in densely populated areas that were further away from rivers.

The estimated coefficients on average annual rainfall and temperature are both positive and significant at $\alpha = 1\%$. These results suggest that densely populated areas with more rainfalls and higher temperature experienced higher income increases.

Table 4.2 GS3SLS coefficient estimates for equations of percentage changes in population, employment and median weekly household income

Variable	Population change			Employment change			Median weekly income change		
	Coefficient	Standard Error		Coefficient	Standard Error		Coefficient	Standard Error	
Endogenous Variable									
Population change				1.189	0.055	***	0.872	0.463	*
Employment change	0.833	0.038	***				-0.728	0.385	*
Income change	0.068	0.054		-0.138	0.065	**			
Spatial lag of population change (λ_1)	-0.083	0.216		0.219	0.270		1.698	0.573	***
Spatial lag of employment change (λ_2)	-0.005	0.186		-0.092	0.233		-1.339	0.499	***
Spatial lag of income change (λ_3)	-0.023	0.060		0.056	0.075		0.402	0.164	***
Exogenous Variable									
Environmental Amenity									
Distance to forest	0.0000798	0.0000460	*	-0.0001027	0.0000575	*	-0.0001968	0.0001368	
Distance to river	-0.0000141	0.0000060	**	0.0000199	0.00000739	***	0.0000528	0.0000166	***
Distance to lake	0.0000093	0.0000044	**	-0.0000113	0.00000551	**	-0.0000138	0.0000135	
Distance to national park	-0.0000505	0.0000478		0.0000617	0.0000599		0.0000864	0.0001421	
Crop area	0.0000014	0.0000035		-0.0000027	0.0000044		-0.0000128	0.0000104	

Table 4.2 (continued)

Variable	Population change		Employment change		Median weekly income change	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Pasture area	-0.0000008	0.0000005 *	0.0000009	0.0000006	0.0000007	0.0000015
Climate Attributes						
Rainfall	-0.0053858	0.0016865 ***	0.0070625	0.0020801 ***	0.017052	0.005132 ***
Temperature	-0.0191247	0.0930530	0.0529844	0.1166391	1.065475	0.375401 ***
Infrastructure Amenity						
Distance to airport	0.000004	0.000008	-0.0000063	0.0000098	-0.0000297	0.0000227
Distance to railway station	0.000020	0.000016	-0.0000252	0.0000195	-0.0000196	0.0000476
Economic and Social Attributes						
Population density in 2001	-0.000562	0.003017				
Employment density in 2001			0.0156304	0.1842747		
Median weekly income in 2001					-0.0144907	0.0069813 **
College graduate in 2001	0.000831	0.001930	-0.0005917	0.0024072	0.0098805	0.0058704 *
Home ownership in 2001	-0.000399	0.000366	0.0005012	0.0004531	0.0001612	0.0011308
Indigenous population in 2001	0.000125	0.000653	-0.0001100	0.0008180	-0.0002502	0.0019718

Table 4.2 (continued)

Variable	**Population change**		**Employment change**		**Median weekly income change**	
	Coefficient	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
				Spatial autoregressive parameter of the error term (ρ)		
Population change	-0.248	0.351				
Employment change			-0.201	0.547		
Median weekly income change					-0.009	0.340
Moran's *I* statistic	0.305	***	0.308	***	0.260	***
RESET F-value	6.82	***	3.20	**	2.61	***
Sargan p-value	34.62		29.45		28.01	
Breusch-Pagan χ^2-value	1.19		1.43		0.42	
R-squared	0.881		0.882		0.848	
Number of observations	153		153		153	

*** indicates that the estimated coefficient is significant at α =1%, ** α =5% and * α =10%.

5. Conclusion

In the study of a first-stage hedonic analysis of private residential home transaction data from the Adelaide metropolitan area, we estimated the implicit values associated with residential amenities, such as open spaces and heavy industry dis-amenities. To estimate these values, it was necessary to collect and assemble extensive datasets on final selling prices of single family residential houses and all the attributes associated with the house, land and neighbourhood across the entire metropolitan area. Local fixed effects were also included in the model to control for any remaining neighbourhood characteristics. The local fixed effects were mapped to summarise the residual value of Adelaide's suburbs.

This chapter has yielded insights into the value of different land uses across the metropolitan area. We highlight the importance of both preserving environmental amenities in existing residential areas and providing open spaces and sporting facilities in new housing developments. Preserving the Parklands and the development of Linear Park is shown to be valuable to households as reflected in their market behaviour and willingness to pay more to be closer to these areas. Pressure will mount to develop the Parklands and Linear Park to meet the growing demands for dwellings and we demonstrate that households place a value on these areas. As the cost of maintaining parks, reserves and conservation areas is a relatively large expense for local government, this research is a first step in supporting planning. Future research could focus on optimising landuse configuration with respect to defining the contribution of open spaces to local tax bases.

In terms of setting priorities for open spaces, this work suggests that reserves that have no facilities have to be larger than average to have positive price effects on property prices. This implies that open space provision in areas of urban expansion should be of larger area and perhaps fewer in number, rather than small "pocket parks". A comprehensive analysis of the cost and benefits would reveal the types of open space developments that are likely to yield positive benefits to a newly developed area.

Our modelling has also identified how households may alter behaviour in response to sustainability-related public policies. For instance, under increasingly severe water restrictions used to reduce water consumption, some substitution between private green space and sporting ovals may be occurring. Reserves with sporting ovals are watered more frequently and our analysis suggests households may be willing to pay more to live closer to these areas. Further our results suggest that nature reserves that are not watered and not managed are not an amenity that households were willing to pay more to live near. We speculate that this may be due to the brown, dry landscape, the risk of fire and the risk posed by snakes. There are implications here for long-term planning of urban infill and expansion. The current climate of reduced water availability and policy focus on reducing urban water consumption has created an additional economic imperative to protect and provide open spaces that are managed and maintained, particularly through regular watering. Doing so could add substantial value to urban development.

Our research provides additional evidence in support of the protection of existing open space and the provision of new open spaces as part of the planning and regulation processes need to support long-term urban growth plans. Local governments can use this study when evaluating the benefits of amenity provision.

In the study of a generalised spatial three-stage least square procedure, we evaluated the effect of environmental amenities on percentage changes in population, employment and income of 153 local government areas in the Murray Darling Basin, Australia.

Estimates from the structural parameters, after accounting for spatial dependencies, show that environmental amenities have a significant role in enhancing economic development in the MDB.

Areas closer to rivers experience more population increase over the period of 2001-2006 and LGAs closer to forests and lakes experience more employment and income growth. Additionally, rapid employment and income growth occur in areas with more rainfalls and higher temperature.

Estimates indicate the positive interdependencies between population and employment growth supporting the findings of Garnett and Lewis (2002), Hailu and Brown (2007) and Wu and Mishra (2008). Our model reveals a significant spatial lag effect only in the income change equation. This suggests that the increase in median income of an LGA is influenced by population and median income growth in neighbouring LGAs.

Among economic and social indicators, the only variable which has a significant role in improving economic development is the population of college graduates. The positive result suggests that higher college graduates lead to higher median income growth. However, our results indicate that the initial state of median income limits economic development in the MDB and this outcome is consistent with Wu and Mishra (2008) and Wu and Gopinath (2008) study in the United States. One possible explanation of this spatial inequality in income in the MDB is that the model is picking up low demand for labour at the suburban and rural locations where the labour costs are high.

These results contribute to the existing international literature and provide a better understanding of the role of environmental amenities in regional economic development. Moreover, these results have implications for Australian government agencies to develop environmental related policies to promote rural economic development. The public policies are more effective in economic development in rural regions with high environmental amenities especially when such policies aim to improve or maintain the healthy state of the environmental amenities.

Further research is required to examine what policy options are currently available to promote economic growth in rural regions on which to base further environmental related policies.

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Appendix 1 Descriptive Statistics of Suburb Fixed Effects

Table A1.1 Descriptive statistics of suburb fixed effects and number of sold properties within each suburb

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Aberfoyle Park	0.01495	0.12137	0	1	612
Adelaide	0.00090	0.03006	0	1	37
Albert Park	0.00156	0.03952	0	1	64
Alberton	0.00178	0.04220	0	1	73
Allenby Gardens	0.00156	0.03952	0	1	64
Angle Park	0.00034	0.01849	0	1	14
Ascot Park	0.00215	0.04632	0	1	88
Ashford	0.00027	0.01639	0	1	11
Athelstone	0.00726	0.08488	0	1	297
Athol Park	0.00066	0.02568	0	1	27
Auldana	0.00039	0.01977	0	1	16
Banksia Park	0.00408	0.06375	0	1	167
Beaumont	0.00345	0.05860	0	1	141
Bedford Park	0.00125	0.03528	0	1	51
Belair	0.00340	0.05818	0	1	139
Bellevue Heights	0.00266	0.05154	0	1	109
Beulah Park	0.00137	0.03697	0	1	56
Beverley	0.00100	0.03164	0	1	41
Birkenhead	0.00242	0.04913	0	1	99
Black Forest	0.00098	0.03125	0	1	40
Blackwood	0.00369	0.06063	0	1	151
Blair Athol	0.00274	0.05224	0	1	112

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Blakeview	0.00662	0.08111	0	1	271
Bowden	0.00037	0.01914	0	1	15
Brahma Lodge	0.00337	0.05797	0	1	138
Brighton	0.00259	0.05083	0	1	106
Broadview	0.00352	0.05922	0	1	144
Brompton	0.00198	0.04445	0	1	81
Brooklyn Park	0.00313	0.05584	0	1	128
Burnside	0.00252	0.05011	0	1	103
Burton	0.00560	0.07460	0	1	229
Camden Park	0.00176	0.04191	0	1	72
Campbelltown	0.00459	0.06762	0	1	188
Chandlers Hill	0.00032	0.01782	0	1	13
Cheltenham	0.00176	0.04191	0	1	72
Christie Downs	0.00973	0.09814	0	1	398
Christies Beach	0.00824	0.09037	0	1	337
Clapham	0.00178	0.04220	0	1	73
Clarence Gardens	0.00232	0.04813	0	1	95
Clarence Park	0.00178	0.04220	0	1	73
Clarendon	0.00005	0.00699	0	1	2
Clearview	0.00411	0.06394	0	1	168
Clovelly Park	0.00266	0.05154	0	1	109
College Park	0.00049	0.02210	0	1	20
Collinswood	0.00100	0.03164	0	1	41
Colonel Light Gardens	0.00303	0.05496	0	1	124
Coromandel Valley	0.00447	0.06672	0	1	183

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Cowandilla	0.00071	0.02661	0	1	29
Craigburn Farm	0.00188	0.04334	0	1	77
Craigmore	0.01884	0.13596	0	1	771
Croydon	0.00090	0.03006	0	1	37
Croydon Park	0.00279	0.05271	0	1	114
Cumberland Park	0.00261	0.05107	0	1	107
Darlington	0.00086	0.02923	0	1	35
Daw Park	0.00239	0.04888	0	1	98
Dernancourt	0.00337	0.05797	0	1	138
Devon Park	0.00061	0.02471	0	1	25
Dover Gardens	0.00215	0.04632	0	1	88
Dry Creek	0.00029	0.01712	0	1	12
Dudley Park	0.00024	0.01563	0	1	10
Dulwich	0.00169	0.04103	0	1	69
Eastwood	0.00095	0.03086	0	1	39
Eden Hills	0.00215	0.04632	0	1	88
Edwardstown	0.00252	0.05011	0	1	103
Elizabeth Vale	0.00330	0.05734	0	1	135
Enfield	0.00425	0.06507	0	1	174
Erindale	0.00117	0.03423	0	1	48
Ethelton	0.00166	0.04073	0	1	68
Evandale	0.00098	0.03125	0	1	40
Evanston	0.00134	0.03664	0	1	55
Evanston Gardens	0.00156	0.03952	0	1	64
Evanston Park	0.00430	0.06544	0	1	176

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Everard Park	0.00037	0.01914	0	1	15
Exeter	0.00071	0.02661	0	1	29
Fairview Park	0.00547	0.07378	0	1	224
Felixstow	0.00066	0.02568	0	1	27
Ferryden Park	0.00257	0.05059	0	1	105
Findon	0.00279	0.05271	0	1	114
Firle	0.00090	0.03006	0	1	37
Fitzroy	0.00049	0.02210	0	1	20
Flagstaff Hill	0.01229	0.11018	0	1	503
Flinders Park	0.00318	0.05627	0	1	130
Forestville	0.00068	0.02615	0	1	28
Frewville	0.00071	0.02661	0	1	29
Fulham	0.00220	0.04685	0	1	90
Fulham Gardens	0.00398	0.06299	0	1	163
Fullarton	0.00254	0.05035	0	1	104
Gawler	0.00054	0.02318	0	1	22
Gawler East	0.00437	0.06599	0	1	179
Gawler South	0.00313	0.05584	0	1	128
Gawler West	0.00046	0.02154	0	1	19
Gepps Cross	0.00073	0.02707	0	1	30
Gilberton	0.00100	0.03164	0	1	41
Gilles Plains	0.00327	0.05713	0	1	134
Gillman	0.00010	0.00989	0	1	4
Glandore	0.00222	0.04710	0	1	91
Glanville	0.00064	0.02520	0	1	26

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Glen Osmond	0.00210	0.04579	0	1	86
Glenalta	0.00195	0.04417	0	1	80
Glenelg	0.00098	0.03125	0	1	40
Glenelg East	0.00291	0.05385	0	1	119
Glenelg North	0.00516	0.07162	0	1	211
Glenelg South	0.00117	0.03423	0	1	48
Glengowrie	0.00396	0.06279	0	1	162
Glenside	0.00120	0.03458	0	1	49
Glenunga	0.00144	0.03794	0	1	59
Glynde	0.00117	0.03423	0	1	48
Golden Grove	0.01073	0.10302	0	1	439
Goodwood	0.00191	0.04362	0	1	78
Grange	0.00340	0.05818	0	1	139
Green Fields	0.00002	0.00494	0	1	1
Greenacres	0.00247	0.04962	0	1	101
Greenwith	0.01317	0.11401	0	1	539
Gulfview Heights	0.00359	0.05983	0	1	147
Hackham West	0.00577	0.07572	0	1	236
Hackney	0.00024	0.01563	0	1	10
Hallett Cove	0.01620	0.12625	0	1	663
Hampstead Gardens	0.00110	0.03314	0	1	45
Happy Valley	0.02427	0.15387	0	1	993
Hawthorn	0.00171	0.04132	0	1	70
Hawthorndene	0.00259	0.05083	0	1	106
Hazelwood Park	0.00220	0.04685	0	1	90

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Heathpool	0.00034	0.01849	0	1	14
Hectorville	0.00171	0.04132	0	1	70
Hendon	0.00127	0.03562	0	1	52
Henley Beach	0.00369	0.06063	0	1	151
Henley Beach South	0.00137	0.03697	0	1	56
Highbury	0.00714	0.08417	0	1	292
Highgate	0.00127	0.03562	0	1	52
Hillbank	0.01581	0.12474	0	1	647
Hillcrest	0.00352	0.05922	0	1	144
Hilton	0.00039	0.01977	0	1	16
Holden Hill	0.00279	0.05271	0	1	114
Hope Valley	0.00596	0.07699	0	1	244
Hove	0.00254	0.05035	0	1	104
Hyde Park	0.00174	0.04162	0	1	71
Ingle Farm	0.00973	0.09814	0	1	398
Joslin	0.00100	0.03164	0	1	41
Kensington	0.00076	0.02751	0	1	31
Kensington Gardens	0.00169	0.04103	0	1	69
Kensington Park	0.00215	0.04632	0	1	88
Kent Town	0.00034	0.01849	0	1	14
Keswick	0.00034	0.01849	0	1	14
Kidman Park	0.00193	0.04390	0	1	79
Kilburn	0.00147	0.03826	0	1	60
Kilkenny	0.00108	0.03277	0	1	44
Kings Park	0.00054	0.02318	0	1	22

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Kingston Park	0.00032	0.01782	0	1	13
Kingswood	0.00137	0.03697	0	1	56
Klemzig	0.00447	0.06672	0	1	183
Kurralta Park	0.00007	0.00856	0	1	3
Largs Bay	0.00415	0.06432	0	1	170
Largs North	0.00305	0.05518	0	1	125
Leabrook	0.00088	0.02965	0	1	36
Linden Park	0.00186	0.04306	0	1	76
Lockleys	0.00411	0.06394	0	1	168
Lower Mitcham	0.00195	0.04417	0	1	80
Lynton	0.00015	0.01211	0	1	6
Macdonald Park	0.00002	0.00494	0	1	1
Magill	0.00652	0.08051	0	1	267
Malvern	0.00249	0.04986	0	1	102
Manningham	0.00152	0.03889	0	1	62
Mansfield Park	0.00108	0.03277	0	1	44
Marden	0.00098	0.03125	0	1	40
Marino	0.00305	0.05518	0	1	125
Marion	0.00261	0.05107	0	1	107
Marleston	0.00044	0.02097	0	1	18
Marryatville	0.00032	0.01782	0	1	13
Maslin Beach	0.00147	0.03826	0	1	60
Mawson Lakes	0.00963	0.09765	0	1	394
Maylands	0.00115	0.03387	0	1	47
Mclaren Flat	0.00391	0.06241	0	1	160

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Medindie	0.00098	0.03125	0	1	40
Medindie Gardens	0.00017	0.01308	0	1	7
Melrose Park	0.00203	0.04499	0	1	83
Mile End	0.00249	0.04986	0	1	102
Millswood	0.00235	0.04838	0	1	96
Mitcham	0.00152	0.03889	0	1	62
Mitchell Park	0.00330	0.05734	0	1	135
Modbury	0.00430	0.06544	0	1	176
Modbury Heights	0.00479	0.06904	0	1	196
Modbury North	0.00674	0.08185	0	1	276
Morphett Vale	0.02791	0.16471	0	1	1,142
Morphettville	0.00191	0.04362	0	1	78
Mount Osmond	0.00005	0.00699	0	1	2
Munno Para	0.00296	0.05430	0	1	121
Myrtle Bank	0.00205	0.04526	0	1	84
Nailsworth	0.00164	0.04043	0	1	67
Netherby	0.00120	0.03458	0	1	49
Newton	0.00308	0.05540	0	1	126
Noarlunga Downs	0.01701	0.12930	0	1	696
North Adelaide	0.00166	0.04073	0	1	68
North Brighton	0.00208	0.04553	0	1	85
North Haven	0.00442	0.06636	0	1	181
North Plympton	0.00122	0.03493	0	1	50
Northfield	0.00362	0.06003	0	1	148
Northgate	0.00364	0.06023	0	1	149

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Norwood	0.00389	0.06221	0	1	159
Novar Gardens	0.00230	0.04787	0	1	94
O'Halloran Hill	0.00308	0.05540	0	1	126
Oakden	0.00384	0.06182	0	1	157
Oaklands Park	0.00205	0.04526	0	1	84
Old Reynella	0.00367	0.06043	0	1	150
Osborne	0.00161	0.04013	0	1	66
Ottoway	0.00174	0.04162	0	1	71
Ovingham	0.00046	0.02154	0	1	19
Panorama	0.00230	0.04787	0	1	94
Para Hills	0.00892	0.09402	0	1	365
Para Hills West	0.00293	0.05407	0	1	120
Para Vista	0.00288	0.05362	0	1	118
Paradise	0.00337	0.05797	0	1	138
Parafield Gardens	0.01266	0.11179	0	1	518
Paralowie	0.02053	0.14179	0	1	840
Park Holme	0.00161	0.04013	0	1	66
Parkside	0.00391	0.06241	0	1	160
Pasadena	0.00183	0.04277	0	1	75
Payneham	0.00120	0.03458	0	1	49
Payneham South	0.00076	0.02751	0	1	31
Pennington	0.00244	0.04937	0	1	100
Peterhead	0.00191	0.04362	0	1	78
Plympton	0.00227	0.04762	0	1	93
Plympton Park	0.00222	0.04710	0	1	91

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Pooraka	0.00684	0.08243	0	1	280
Port Adelaide	0.00083	0.02881	0	1	34
Port Noarlunga South	0.01063	0.10255	0	1	435
Port Willunga	0.00845	0.09156	0	1	346
Prospect	0.01156	0.10689	0	1	473
Queenstown	0.00147	0.03826	0	1	60
Redwood Park	0.00723	0.08474	0	1	296
Reid	0.00002	0.00494	0	1	1
Renown Park	0.00115	0.03387	0	1	47
Reynella	0.00547	0.07378	0	1	224
Reynella East	0.00305	0.05518	0	1	125
Richmond	0.00188	0.04334	0	1	77
Ridgehaven	0.00398	0.06299	0	1	163
Ridleyton	0.00081	0.02839	0	1	33
Rose Park	0.00073	0.02707	0	1	30
Rosewater	0.00386	0.06202	0	1	158
Rosslyn Park	0.00103	0.03202	0	1	42
Rostrevor	0.00552	0.07411	0	1	226
Royal Park	0.00310	0.05562	0	1	127
Royston Park	0.00103	0.03202	0	1	42
Saint Agnes	0.00281	0.05294	0	1	115
Saint Georges	0.00166	0.04073	0	1	68
Saint Marys	0.00203	0.04499	0	1	83
Saint Morris	0.00108	0.03277	0	1	44
Saint Peters	0.00249	0.04986	0	1	102

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Salisbury	0.00711	0.08403	0	1	291
Salisbury Downs	0.00369	0.06063	0	1	151
Salisbury East	0.00973	0.09814	0	1	398
Salisbury Heights	0.00440	0.06618	0	1	180
Salisbury North	0.00760	0.08685	0	1	311
Salisbury Park	0.00181	0.04249	0	1	74
Salisbury Plain	0.00120	0.03458	0	1	49
Seacliff	0.00200	0.04472	0	1	82
Seacliff Park	0.00195	0.04417	0	1	80
Seacombe Gardens	0.00210	0.04579	0	1	86
Seacombe Heights	0.00169	0.04103	0	1	69
Seaford Meadows	0.00002	0.00494	0	1	1
Seaton	0.00608	0.07777	0	1	249
Seaview Downs	0.00374	0.06103	0	1	153
Sefton Park	0.00105	0.03240	0	1	43
Semaphore	0.00298	0.05452	0	1	122
Semaphore Park	0.00279	0.05271	0	1	114
Semaphore South	0.00105	0.03240	0	1	43
Sheidow Park	0.00902	0.09453	0	1	369
Skye	0.00005	0.00699	0	1	2
Smithfield	0.00758	0.08671	0	1	310
Somerton Park	0.00486	0.06956	0	1	199
South Brighton	0.00249	0.04986	0	1	102
South Plympton	0.00347	0.05880	0	1	142
Springfield	0.00037	0.01914	0	1	15

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Stepney	0.00066	0.02568	0	1	27
Stonyfell	0.00093	0.03046	0	1	38
Sturt	0.00200	0.04472	0	1	82
Surrey Downs	0.00455	0.06727	0	1	186
Taperoo	0.00203	0.04499	0	1	83
Tea Tree Gully	0.00279	0.05271	0	1	114
Tennyson	0.00073	0.02707	0	1	30
Thebarton	0.00105	0.03240	0	1	43
Thorngate	0.00015	0.01211	0	1	6
Toorak Gardens	0.00176	0.04191	0	1	72
Torrens Park	0.00235	0.04838	0	1	96
Torrensville	0.00217	0.04658	0	1	89
Tranmere	0.00276	0.05248	0	1	113
Trinity Gardens	0.00078	0.02795	0	1	32
Trott Park	0.00337	0.05797	0	1	138
Tusmore	0.00093	0.03046	0	1	38
Underdale	0.00134	0.03664	0	1	55
Unley	0.00257	0.05059	0	1	105
Unley Park	0.00134	0.03664	0	1	55
Urrbrae	0.00071	0.02661	0	1	29
Vale Park	0.00181	0.04249	0	1	74
Valley View	0.00633	0.07930	0	1	259
Vista	0.00095	0.03086	0	1	39
Walkerville	0.00195	0.04417	0	1	80
Walkley Heights	0.00450	0.06690	0	1	184

Variable	Mean	Standard Deviation	Min	Max	Number of Properties Sold in Each Suburb
Warradale	0.00425	0.06507	0	1	174
Waterfall Gully	0.00005	0.00699	0	1	2
Wattle Park	0.00220	0.04685	0	1	90
Wayville	0.00093	0.03046	0	1	38
Welland	0.00059	0.02421	0	1	24
West Beach	0.00425	0.06507	0	1	174
West Croydon	0.00349	0.05901	0	1	143
West Hindmarsh	0.00125	0.03528	0	1	51
West Lakes	0.00335	0.05776	0	1	137
West Lakes Shore	0.00183	0.04277	0	1	75
West Richmond	0.00139	0.03730	0	1	57
Westbourne Park	0.00188	0.04334	0	1	77
Willaston	0.00376	0.06123	0	1	154
Willunga	0.00183	0.04277	0	1	75
Windsor Gardens	0.00611	0.07792	0	1	250
Wingfield	0.00037	0.01914	0	1	15
Woodcroft	0.01415	0.11810	0	1	579
Woodville	0.00122	0.03493	0	1	50
Woodville Gardens	0.00078	0.02795	0	1	32
Woodville North	0.00149	0.03858	0	1	61
Woodville Park	0.00110	0.03314	0	1	45
Woodville South	0.00283	0.05317	0	1	116
Woodville West	0.00195	0.04417	0	1	80
Wynn Vale	0.00824	0.09037	0	1	337
Yatala Vale	0.00005	0.00699	0	1	2

Note The statistics are based on estimation sample of 40,932 private residential dwellings sold in the Adelaide metropolitan area during January 2005 to June 2008.

Appendix 2 Spatial Lag Hedonic Model without Fixed Effects – Sensitivity Check

Table A2.1 Estimated coefficients on proximity to the nearest reserve or national park with a sporting facility at level 3 and tougher level 3 water restrictions

Dependent Variable: lnprice	Coefficient	Standard Error	
Environmental Amenity			
ln (Distance to reserve – sport) × Level 3 restrictions	0.00448	0.00265	*
ln (Distance to reserve – sport) × Tougher level 3 restrictions	-0.00437	0.00228	*
ln (Distance to national park – sport) × Level 3 restrictions	-0.00894	0.00277	***
ln (Distance to national park – sport) × Tougher level 3 restrictions	-0.01386	0.00251	***

*** indicates that the estimated coefficient is significant at α =1% and * α =10%.

Appendix 3 Outputs of the Research

I would like to list the outputs that produced during my PhD candidature and state my contributions and those of the co-authors into each output from my thesis in terms of the conceptualisation, realisation and documentation of the study. The outputs include one working paper, one published paper and three manuscripts. The published paper titled "The Value of Public and Private Green Spaces under Water Restrictions" and one working paper with the title of "Natural Amenities and Regional Economic Growth in Australia: A Spatial Three-Stage Least Square Analysis of Population, Employment and Income Change" are not included in this thesis as I was not the first author. The thesis contains the following working papers and manuscript:

Parvin Mahmoudi, Darla Hatton MacDonald, Andrea Cast, Literature Review of Hedonic Property Value Models for the Valuation of Environmental Attributes, Project Report for Water for Healthy Country Flagship, CSIRO Land and Water, July 2008.

Parvin Mahmoudi, Darla Hatton MacDonald, Neville D. Crossman, David M. Summers, John van der Hoek, Space Matters: The Importance of Amenity in Planning Metropolitan Growth, Submitted to the Australian Journal of Agricultural and Resource Economics on 9 June 2011.

Parvin Mahmoudi, Sorada Tapsuwan, Darran King, The Effects of Environmental, Social and Economic Amenities on Economic Development in Rural Australia: Estimation of a Spatial Simultaneous System of Equations, Yet to be submitted.

In 2008, I reviewed the literature on the hedonic pricing model and documented all the draft and final reports for the working paper on Literature Review of Hedonic Property Value Models for the Valuation of Environmental Attributes. I received guidance and comments from Dr Darla Hatton

MacDonald as my supervisor at the time. Furthermore, Dr Andrea cast trained me on how to structure a project report in general and provided me with editorial assistance.

For manuscript 1, I reviewed the literature, selected variables for the spatial hedonic model, collected the property data and constructed the weight matrix using GeoDa, conducted entire modelling including various test statistics and analysed the results and wrote the draft of the manuscript. Darla Hatton MacDonald provided guidance and comments to the earlier versions of modelling and the draft report, wrote the study area section jointly with Parvin for the earlier versions of the draft reports and reworded the conclusion section of the manuscript. Neville Crossman reworded the manuscript's introduction at which my literature review was incorporated. David Summer compiled the GIS data based on my variables selection, wrote the construction method of GIS data and produced maps for the manuscript. John Van der Hoek demonstrated that Maximum likelihood Estimator is unbiased and efficient and provided his guidance on the spatial model.

This manuscript is the extension of the published paper in several aspects. First, it is the inclusion of a wider range of structural, locational and environmental attributes. Second, the study area is not limited to the eastern side of the Adelaide metropolitan area but the data collected for the whole Adelaide metropolitan region. Finally, it is the significant improvement in modelling where the Maximum Likelihood estimation technique is applied to the spatial lag hedonic model with fixed effects to obtain unbiased and consistent estimators.

For manuscript 2, I developed the research proposal, reviewed the literature, conducted entire modelling including construction of the weight matrix using Stata, developed a spreadsheet to construct spatial lag variables, wrote do files within Stata to conduct various test statistics and estimate the simultaneous system of equations using GS3SLS technique, selected instruments for endogenous dependent variables and wrote the manuscript and included the study site section that was written by Darran. Sorada Tapsuwan wrote the introduction and the estimation results sections for the earlier versions of draft report jointly with Parvin. Darran King collected the GID data, wrote the study site section for the earlier versions of draft report and produced study area map for the manuscript.

This study was successful to estimate the influences of several measures of environmental amenity on population, employment and median income change, but the Tapsuwan (2011) study failed to demonstrate. The improvement in the research is due to a better selection of instruments for the endogenous dependent variables.

My overall contributions were more significant than those of the other co-authors. This is indicated by the order of authorship of the manuscripts. I am the first author of the working paper and the two manuscripts that included in this thesis.

The following two outputs which are not included in this thesis:

Darla Hatton MacDonald, Neville D. Crossman, Parvin Mahmoudi, Laura O. Taylor, David M. Summers, Peter C. Boxall, (2010). The Value of Public and Private Green Spaces under Water Restrictions, *Landscape and Urban Planning* 95, 192–200.

Sorada Tapsuwan, Parvin Mahmoudi, Darran King, Md. Sayed Iftekhar (2011), Natural Amenities and Regional Economic Growth in Australia: A Spatial Three-Stage Least Square Analysis of Population, Employment and Income Change, Working Paper, CSIRO Sustainable Ecosystem.

For this manuscript, I wrote the research proposal, reviewed the literature jointly with Sorada Tapsuwan, selected variables, conducted earlier versions of modelling jointly with Sorada Tapsuwan and wrote the estimation technique section. Sorada Tapsuwan reviewed the literature jointly with Parvin Mahmoudi, conducted earlier versions of modelling jointly with Parvin Mahmoudi, conducted final modelling and wrote the manuscript at which the estimation technique and study site sections written, respectively, by Parvin Mahmoudi and Darran King were integrated. Darran King collected the GID data, wrote the study site section and produce study area map. Sayed Iftekhar completed the literature review and integrated it to the draft manuscript.