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Tropical Vegetation and Residential Property Value: A Hedonic Pricing Analysis in Singapore

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A B S T R A C T

Effective urban planning depends on knowing homebuyers' preferences for neighbourhood features that provide different amenities, such as managed parks and trees. As the expansion of tropical urban areas into biodiversity hotspots is predicted to more than double by 2030, knowing homebuyers utility from different vegetation types can contribute to global biodiversity conservation strategies. We used the hedonic pricing method to estimate the economic value of managed, spontaneous and high conservation value vegetation to Singapore public housing using a mixed effects model. On average vegetation had positive effects on property selling price, accounting for 3% of the average property's value, or a total of S$179 million for all public housing apartments sold over 13 months. These effects were almost entirely driven by managed vegetation, which had positive marginal effects on price for 98.1% of properties. The estimated marginal effects of high conservation value vegetation were mostly negative (90.5%% properties), but positive for properties without much managed vegetation nearby. The estimated marginal effects of spontaneous vegetation were mixed and mostly small. To reconcile the goals of protecting high conservation value vegetation and maximising homeowner utility, new public housing developments should contain more managed vegetation but be away from high conservation value vegetation.

1. Introduction

Vegetation provides services to society that are often not quantified, and are subsequently undervalued in land-use decision making (Daily et al., 2009). Various stated and revealed preference methods exist to determine vegetation value, including the hedonic pricing method applied to residential property selling prices. The hedonic pricing method assesses how different combinations of neighbourhood, structural and environmental characteristics (including neighbourhood vegetation) influence the price consumers are willing to pay for a property (Rosen, 1974). Vegetation variables are commonly included in hedonic pricing analyses because vegetation provides positive amenities in the form of ecosystem services, which include aesthetic value, recreation, mitigation of the urban heat island effect and improvement in air quality.

Proximity to nature areas has been identified as an important determinant of property price around the world, with recreational parks having clearer positive effects than forest. In a review of the literature, we found that distance to the nearest recreational park was identified having positive and statistically significant effects on house prices eight times (Cho et al., 2006, 2009b; Kaufman and Cloutier, 2006; Poudyal et al., 2009; Sander and Polasky, 2009; Song and Knaap, 2004; Troy and Grove, 2008; Tyrvainen, 1997) and insignificant effects four times (Cho et al., 2009a; Kong et al., 2007; Mahan et al., 2000; Nicholls and Crompton, 2005), whereas distance to nearest forest was positive and statistically significant twice (Mansfield et al., 2005; Tyrvainen and Miettinen, 2000) and insignificant six times (Irwin, 2002; Jim and Chen, 2006; Kong et al., 2007; Mueller and Loomis, 2008; Powe et al., 1997; Tyrvainen, 1997). In South China and Hong Kong, similar effects of nearby vegetation on property price were observed. Metrics of park quantity or accessibility were significant in all three studies that considered it (Chan et al., 2008; Chen and Jim, 2010; Jim and Chen, 2010). In two of these studies the presence of a park within a neighbourhood explained 10–11% and 15% of property price, respectively (Chan et al., 2008; Jim and Chen, 2010). The quantity of woodlands was considered in one study and found not to have a statistically significant effect (Jim and Chen, 2006).

However few of these studies were conducted in tropical areas. Of 83 hedonic-pricing studies we identified (see supplementary material for full list of references) that included vegetation as an explanatory variable, 61 were in temperate ecozones (as defined by Breckle, 2002) while only six were found in tropical ecozones (five in Hong Kong or Guangdong; one in Brazil), the remaining fifteen studies were located in

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Mediterranean forests, woodlands and scrub (9); deserts and xeric shrublands (4); and boreal forests and taiga (2).

The lack of knowledge about homebuyer's preferences for neighbourhood vegetation in tropical areas needs to be addressed directly, because preferences are known to vary geographically and estimated values cannot be simply transferred from other regions (Brander and Koetse, 2011). For example, one study in a desert ecozone found that neighbourhood greenness was the variable with the strongest effect on property selling price, potentially due to greenness naturally being a rarer feature in the desert landscape (Bark et al., 2009). This contrasts with temperate forest ecozones where vegetation is commonly not the most important variable (property structural characteristics are more influential). One possible reason differences exist between the tropics and other locations is that ecosystem services (or, in some cases, disservices) relevant to homebuyers vary in type and magnitude across ecozones. For example, urban forests in tropical areas can cool the climate through evapotranspiration and shade. In tropical Singapore the difference in temperature between a forest and urban location can be up to ~7 °C, (Roth and Chow, 2012), enough to moderate the urban heat island effect and dramatically reduce the risk of heat stress in cities where the temperature is regularly > 30 °C (Makaremi et al., 2012). In contrast, the urban heat island effect in temperate locations can have either a positive or negative effect depending on the time of year. More information about the economic value of natural vegetation to residents of tropical cities is needed to ensure a fair and efficient planning process in these cities.

The need to understand homebuyers' preferences for vegetation in tropical cities is also important for biodiversity conservation. Tropical areas have high biodiversity and are urbanising rapidly. In the period 1980–2000 the urbanisation rate in tropical cities was 3.3% per year, more than one third higher than in the rest of the world (Edelman et al., 2014). In the tropical city-state of Singapore, for example, the government plans to further urbanise by constructing 700,000 new public apartments by 2030 (Singapore Government, 2013). If tropical homebuyers have a preference for living near a particular type of vegetation, this could aid biodiversity conservation efforts, provided that these preferences are known and communicated to developers or planners. In this study, we use Singapore as a case study on which to apply the hedonic pricing method and estimate tropical homebuyers' preferences for different types of nearby vegetation.

1.1. Background to Singapore's Housing Market and Homebuyers Preferences

Singapore is a city-state in Southeast Asia. With its tropical location, just over 1° north of the equator, and its highly urbanised environment, Singapore provides an opportunity to study the effects of vegetation on house prices in a tropical city (Fig. 1).

Singapore's housing market consists of both privately and publicly built properties, the planning (zoning) and approval of which is the responsibility of the Redevelopment Authority (URA), which makes all Singapore's planning decisions. Around 80% of households in Singapore (over one million) are public housing apartments developed by the Housing and Development Board (Department of Statistics Singapore, 2016). Each public housing town comprises high-rise residential blocks, often reaching > 20 floors in height. Public housing apartments within these blocks come in six major types, each of which has uniform structural characteristics, including the number of bedrooms and bathrooms, and approximate floor area. Approximately 86% of properties are three-, four- or five-room apartments. Ownership of public housing apartments within these blocks is on a leasehold basis, with the majority of residents having 99-year leases. After this period an apartment's ownership legally returns to the state. However, five years after the first owner moves in, the lease may be resold to a private buyer. This creates a large resale market for government-built and subsidised housing. The next largest group of properties (approximately 14% of Singapore households) is leasehold or freehold condominiums, which typically include extra facilities such as security guards, swimming pools and gyms. Finally, 5% of households are terraced, semi-detached or detached houses, known locally as landed properties (Department of Statistics Singapore, 2016).

Previous hedonic pricing studies in Singapore have not included vegetation-related variables. Andersson (2000) found that floor area had a very strong positive effect on house price in Singapore (accounting for 79% of the variance), with year of construction and percentage of expatriates in each condominium having weaker positive effects and distance to central Singapore having a weak negative effect (Andersson, 2000). Another Singapore study (Sue and Wong, 2010) found that variables having positive effects on house prices were floor area, public housing apartment type, apartment storey, upgrading plan, being within 1 km of a train station and being within 1 km of a school that has good academic performance.

The results from hedonic pricing studies in Singapore are generally corroborated by survey data. One survey found that transportation networks, location within Singapore (being close to the centre of a public housing town and to estate facilities) and provision of public housing estate facilities (such as retail shops, eateries and cooked food centres, transportation networks in estate, education, health related and financial related) were the most frequently cited positive aspects of public housing blocks, and that poor cleanliness/maintenance, noise and poor lift services were the most frequently cited negative aspects (Housing Development Board, 2008). Another survey found that being located close to central Singapore was the most important determinant of apartment choice, while other important aspects of properties were proximity to commercial areas, train stations and bus interchange stations, and being located on an intermediate level of a building (Yuen, 2005). A third survey assessed preferences for environmentally friendly buildings in the private housing market in Singapore (Heinzle et al., 2013). Consumers were willing to pay a premium equivalent to 20% of a property's value based on floor area, 12% for location, and 3% for proximity to commercial areas. In addition, Singaporean buyers were willing to pay an extra 8% for an apartment that is in a building with official green building certification (greenmark platinum).

2. Materials and Methods

The study area was Singapore, specifically the mainland and any island connected to it by road as of January 2014. Resale data on 15,962 public housing apartments in Singapore dating from the start of April 2013 to the end of April 2014 were deflated to a base time of April 2013 using monthly property price consumer index values produced by the Singapore Government (Singapore Government, 2014). Each public housing apartment location was geocoded using the Google API service V3, which accurately identifies point location to within 2.64 m (Benker et al., 2011). None of these properties had land attached to them. Euclidean distance of each property to all "distance to" variables and the proportion of vegetation types and sea/fresh water within each public housing neighbourhood buffer (1600 m) was calculated using ArcGIS 10 (ESRI, 2010). A 1600 m buffer was calculated as this is a commonly used metric for easy walking distance (Cohen et al., 2006; Jago et al., 2006; Norman et al., 2006). We excluded apartments with a model category of "multi-generational" because the small sample size prevented model convergence (five apartments in total). Summary statistics and sources of information for all variables used in the maximal model can be found in Table 1.

2.1. Explanatory Variables

When designing hedonic-pricing studies of property prices, selection of explanatory variables should be informed by previous research (Cho et al., 2009b, 2008; Kong et al., 2007; Mansfield et al., 2005; Song and Knaap, 2004), subject to constraints of data availability (Cho et al.,

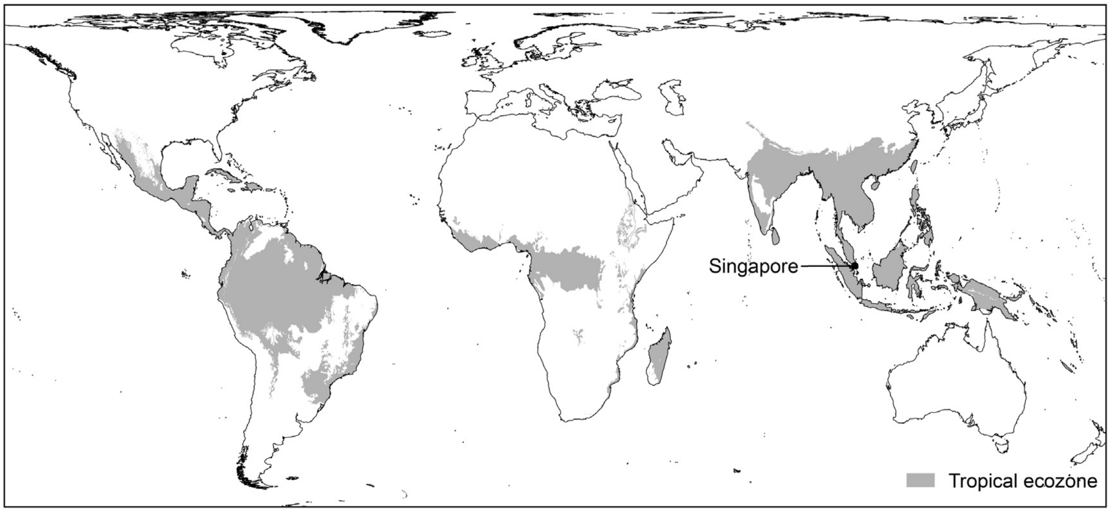

Fig. 1. Location of Singapore within the tropical ecozone.

2009b; Doss and Taff, 1996; Jim and Chen, 2006; Kaufman and Cloutier, 2006; Kong et al., 2007; Mansfield et al., 2005; Mueller and Loomis, 2008; Poudyal et al., 2009; Troy and Grove, 2008). We followed this approach here.

2.1.1. Structural Characteristics

Property structural characteristics are consistently identified as important determinants of property price around the world. Most hedonic pricing studies are from cities in Europe and the United States, but five studies from Asia (Hong Kong and South China) report results consistent with the global pattern (Chan et al., 2008; Chen and Jim, 2010; Jim and Chen, 2010, 2009, 2006). Floor area had the largest effects size in three of the five Asian studies (Jim and Chen, 2010, 2009, 2006). Apartment storey was also statistically significant in all five studies conducted in Asia and number of rooms was statistically significant in two out of the three studies in which it was included as a variable. Apartment storey within a public housing block was also found to affect stated and revealed preferences in two Singapore-based studies (Heinzle et al., 2013; Sue and Wong, 2010). Therefore in our maximal model we included the following structural characteristics as explanatory variables: floor area, apartment type (number of rooms), apartment model (arrangement of apartment); apartment age and storey.

2.1.2. Neighbourhood Characteristics

We included several explanatory variables expressing straight line (Euclidean) distance to amenities. We included distance to the city's central area, because previous studies have identified it as an important determinant of house price in Singapore (Yuen, 2005) and other cities in Asia (Jim and Chen, 2006). We included distance to nearest shopping mall, which has previously been shown to influence prices of public housing (Yuen, 2005) and private (Heinzle et al., 2013) apartment in Singapore. We included distance to nearest government-managed cooked food centre (hawker centre). These centres sell affordable hot food, drinks and local produce: 50% of Singaporeans visit a cooked food centre at least six times a week (Health Promotion Board, 2004) and the centres often substitute for home cooking (Henderson, 2010). Distance to train station (MRT station) was included because it is the most commonly used method of transportation in Singapore (Jim and Chen, 2006) and was previously found to be a determinant of property preference in Singapore (Heinzle et al., 2013; Sue and Wong, 2010). We also included distance to bus interchange based on past evidence (Yuen, 2005). We included distance to coastline as an explanatory variable, because coastlines provide amenities such as scenic views. Our final Euclidean distance-related variable was distance to nearest motorway: motorways are associated with noise and air pollution and can have a negative effect on property selling price (Jim and Chen, 2006; Tajima, 2003).

We also included a number of categorical distance-based variables. One was a categorical variable indicating whether an apartment was within 1 km or within 2 km of a good primary school. We defined a good school as one that has been awarded the national School of Excellence award or the national School of Distinction award (Ministry of Education Singapore, 2014). The distance bands were used because Singapore residents living within 1 km of a primary school are given first priority for student admission, while residents living within 2 km are given second priority (Ministry of Education Singapore, 2017). Proximity to a top primary school has been shown to influence house prices within Singapore and globally (Sue and Wong, 2010).

Another variable that has been shown to (positively) affect property prices is the quantity of water bodies (e.g. rivers and lakes) in the neighbourhood (Cho et al., 2009b, 2006; Jim and Chen, 2006; Sander and Polasky, 2009). In Singapore this may also be the case, because water bodies provide scenic views, and because walkways around them are frequented by runners. Therefore, we included the quantity of freshwater within a 1600 m buffer (easy walking distance) as an explanatory variable.

To account for the possibility that apartment prices are driven by recreational facilities in parks, rather than vegetation per se, we included the richness of park/national park facilities within a 1600 m buffer as a variable. Park facilities in a neighbourhood have been found to have a strong correlation with property price in the US (Leonard et al., 2015). The park facilities information was taken from Singapore government data (National Parks Board, 2017). From this dataset we removed access points, car parks and campsites, as these would not provide utility to homebuyers living within walking distance. We also removed water bodies because this was represented by the freshwater variable and lawn because it was represented by the managed vegetation variable (see below). Lastly wheelchair access was removed, as most Singapore parks are informally accessible by wheelchair even though this may not be officially stated.

2.2. Vegetation Variables

For vegetation, the key focus of our study, our selection of variables was informed by past research into the relationship between greenspace and house prices. Vegetation in and around cities has been positively related to property selling price in other parts of the world (Mansfield et al., 2005; Siriwardena et al., 2016; Tyrvainen and Miettinen, 2000). The ecosystem services provided by vegetation include mitigation of

Table 1
Dependent variable (apartment selling price) explanatory variables (included fixed and random effects) used in the different hedonic regressions, along with their mean values, median values and, for explanatory variables, the expected relationships with the dependent variable: n/a = not applicable; + = a positive relationship; − = a negative relationship; ± = uncertain.

Variable	Description	Mean	Median	Source	Expected effect direction
Dependent variable					
Apartment selling price	Monthly deflated resale price for all public housing apartments sold from April 2013 to April 2014 in Singapore dollars (S$).	373,926	356,944	(Housing and Development Board, 2014)	n/a
Vegetation variables					
Percentage of high conservation value vegetation in 1600 m buffer (highcon vegetation)	Percentage of primary dipterocarp forest, old secondary forest, mangrove forest, freshwater swamp forest and freshwater marsh in a 1600 m radius buffer (%).	0.2	0	(Yee et al., 2011)	+
Percentage of managed vegetation in 1600 m buffer (managed vegetation)	Percentage of managed vegetation in a 1600 m radius buffer (%).	37.5	37.4	(Yee et al., 2011)	+
Percentage of spontaneous vegetation in 1600 m buffer (spontaneous vegetation)	Percentage of young secondary forest and scrubland in a 1600 m radius buffer (%).	12.9	10.5	(Yee et al., 2011)	+
Managed vegetation:spontaneous vegetation	Interaction term between managed vegetation and spontaneous vegetation.	n/a	n/a	(Yee et al., 2011)	+
Managed vegetation:highcon vegetation	Interaction term between manages vegetation and high conservation value vegetation.	n/a	n/a	(Yee et al., 2011)	+
Spontaneous vegetation: highcon vegetation	Interaction term between spontaneous vegetation and high conservation value vegetation.	n/a	n/a	(Yee et al., 2011)	+
Other explanatory variables					
Percentage of freshwater in 1600 m buffer (freshwater)	Percentage of freshwater including reservoirs, natural rivers, engineered rivers and canals in a 1600 m radius buffer (%).	207	0	(Yee et al., 2011)	+
Richness of park facilities in 1600 m buffer (park facilities richness)	Richness of park facilities within 1600 m from each property. This includes playgrounds, bicycle rental facilities among others (m).	4.843	5	data.gov.sg	+
Within catchment of top primary school – 1000 m or 2000 m	Whether a property is located within 1000 m 2000 m or outside catchment boundaries of a primary school with either a School of Excellence (SEA) or School of Distinction (SDA) award ranked by the 2013 government positing exercise (categorical).	n/a	n/a	moe.gov.sg	n/a
Distance to central area	Distance to the central area (central business district and main commercial centre) defined by Singapore's Urban Redevelopment Authority (m).	8850	1540	ura.gov.sg	−
Distance to nearest cooked food centre	Distance to nearest cooked food centre from apartment (m).	1540	947	data.gov.sg	−
Distance to nearest train station	Distance to nearest train metro station including interchanges but excluding Light Rail Transit (LRT) (m).	798	727	data.gov.sg	−
Distance to nearest bus interchange	Distance to one of the 22 bus interchanges defined by the Singapore LTA (Land Transport Authority, 2013) (m).	1281	1144	sbstransit.com.sg	−
Distance to nearest major shopping mall	Distance to nearest major shopping mall (m).	1122	1006	mallsg.com	−
Distance to nearest motorway	Distance to nearest motorway in Singapore (m).	940	639	openstreetmap.org	±
Distance to coastline	Distance to nearest part of Singapore's coastline (m).	3571	3201	(Yee et al., 2011)	−
Time since lease commencement	A proxy for the age of the apartment, commonly years since built +1. Years since public housing 99 year lease was originally issued by the government (years).	24.74	26	(Housing and Development Board, 2014)	+
Floor area	Apartment floor area (m^2).	95	93	(Housing and Development Board, 2014).	+
Apartment type	A proxy for the number of rooms and other apartment structural characteristics (1 Room, 2 Room, 3 Room, 4 Room, 5 Room, Executive) (categorical).	n/a	n/a	(Housing and Development Board, 2014)	n/a
Storey category	Floor storey group (1–5, 6–10, 11–15, 16–20, 21–25, 26–30, 31–35, 36–40) (categorical).	n/a	n/a	(Housing and Development Board, 2014)	n/a
Apartment model	A dummy coded proxy for the quality/grade of the apartment (Adjoined Apartment, Apartment, Dbss, Improved, Maisonette Model A, Model A-Maisonette, Model A2, New Generation Premium Apartment, Premium Maisonette, Simplified Standard) (categorical).	n/a	n/a	(Housing and Development Board, 2014)	n/a
Random effects					
Apartment public housing town, street and block	A random intercept to allow for error variance at three spatial scales: public housing town, street nested within public housing town, and block nested within street, nested within public housing town.	n/a	n/a	(Housing and Development Board, 2014)	n/a
Year and month of apartment sale	A random intercept to allow for error variance nested at two temporal units: year and year nested within month of sale.	n/a	n/a	(Housing and Development Board, 2014)	n/a

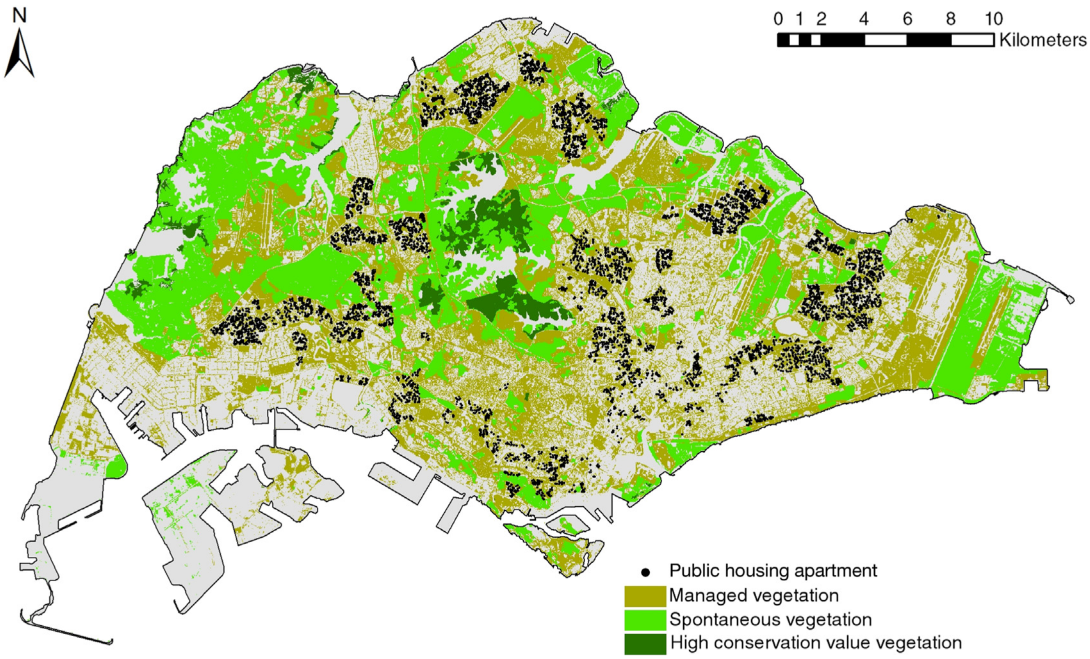

Fig. 2. Map showing the spatial distribution of vegetation types used (Yee et al., 2011) and public housing apartment locations (Housing and Development Board, 2014).

the urban heat island effect, reduction of overland surface runoff, improvement of air quality, and provision of psychological and cultural benefits (Akbari et al., 2001; Dimoudi and Nikolopoulou, 2003; Pataki et al., 2011; Roth and Chow, 2012). But there are also potential disamenity effects of vegetation, including the presence of mosquitoes and animals perceived as dangerous (e.g., snakes and monkeys). Importantly, the effect of vegetation on property price can differ by vegetation type (Bark et al., 2009; Cho et al., 2009b, 2008; Troy and Grove, 2008), and the effects of different types of vegetation may not be independent of one another. For example, in a neighbourhood with abundant managed parks, there may be little perceived benefit to natural vegetation. All of these considerations point to the need to consider not only vegetation quantity but also vegetation type in hedonic pricing studies (Ashcroft and Major, 2013; Caryl et al., 2013; Werner, 2011).

Our vegetation variables were derived from a comprehensive vegetation survey previously completed in Singapore (Yee et al., 2011). Using ArcGIS 10, we classified eight vegetation classes identified by Yee et al. (2011) (Fig. 2) into three levels, based on their conservation value: high conservation value vegetation, managed vegetation and spontaneous vegetation (see below) (ESRI, 2010). We then calculated the percentage of each vegetation type in a 1600 m radius buffer around each property. Because the utilities of different vegetation types may not be independent, we included an interaction term between each pair of vegetation types in our model. The resolution of the vegetation data was 100 m^2, with each pixel representing the majority land cover in that pixel.

2.2.1. High Conservation Value Vegetation

We defined high conservation value vegetation as primary forest, freshwater swamp forest, mangrove forest, freshwater marsh or old secondary forest, using classifications by Yee et al. (2011). Primary forest in Singapore comprises a very small percentage of land area (around 0.2%, 118 ha), all of which is located in the Central Catchment and Bukit Timah Nature Reserves. The freshwater swamp forest in Singapore consists of small areas in the Nee Soon Swamp Forest and less-studied parts of western Singapore. Freshwater marsh habitats are mostly found within the western catchment of Singapore. Primary forest and freshwater swamp forest and freshwater marshes support the highest levels of biodiversity and contain the largest proportion of native species in mainland Singapore, both important metrics of conservation value (Appleton, 2013). All of the mangrove and freshwater marsh forests in mainland Singapore are located along the northern coast of the island. While mangroves typically have lower biodiversity than other terrestrial vegetation types, they provide important habitats for unique intertidal and aquatic species. Much of Singapore's old secondary forest is located within the Central Catchment Nature Reserve, in the geographic centre of the nation, and contains a mixture of native and exotic species. The high level of biodiversity within this vegetation type can provide both ecosystem services and disservices, which may affect homebuyer's utility of this green space and green space around it (see details below).

In Singapore much of the high conservation value vegetation has already been lost, including mangroves, which once covered large stretches of the coastline, and primary forest, which covered most of the island (Corlett, 1992). This has led the National Parks Board to introduce comparable recreational activities into different types of rare high conservation value areas, such as nature watching areas and nature walks. Examples of these walks are the Pasir Ris and Sungei Buloh mangrove boardwalks; and the Bukit Timah and central catchment nature reserve nature trails, among primary and old secondary forest. A disservice of this type of vegetation in Singapore can be human–wildlife conflict between residents and snakes, macaques and other types of biodiversity. The majority of the macaque population in Singapore (70%) is located in the Central Catchment and Bukit Timah Nature Reserves, where the majority of high conservation value vegetation is found. Furthermore, at least 50% of the macaque population in Singapore obtains some food from anthropogenic sources and tends to be distributed along forest edges (Sha et al., 2009a).

2.2.2. Managed Vegetation

We defined managed vegetation as classified by Yee et al. (2011). Singapore public parks make up ~11% of urban managed greenspace, with roadside greenery making up ~13%. The remaining 76% of urban managed greenspaces include vacant land plots with trimmed grass, park connectors, and vegetation found throughout public housing estates and condominiums (Tan et al., 2013). Singapore has applied a three-tiered system to park planning to ensure an even distribution of green space around public housing towns: precinct gardens, neighbourhood parks and town parks. The plants inside these parks also provided ecosystem services to homebuyers, the most important being reducing solar radiation on the ground through shade trees and improving the aesthetic value of an area. But some of the utility value of parks is associated with features other than vegetation, such as playground facilities and playing fields. Golf courses also constitute a significant proportion of managed vegetation in Singapore, approximately 2.2%, which is ~8% of all managed vegetation (Neo and Savage, 2002). Roadside greenery is commonly found in the form of street trees, which can reduce solar radiation alongside walkways (Richards and Edwards, 2017). Previous research has shown that Singapore residents appreciate managed vegetation landscapes (Henderson, 2013; Yuen et al., 1996) and specifically find them more aesthetically pleasing then other vegetation types (Khew et al., 2014).

2.2.3. Spontaneous Vegetation

We defined spontaneous vegetation as scrubland and young secondary forest as classified by Yee et al. (2011). Singapore's scrubland is the earliest age of spontaneous vegetation identified. Broadly, scrubland includes two types of habitat, either areas of initial secondary successional vegetation around Changi airport, to the far east of Singapore and the north-east coast, or smaller patches of early forest gap-phase vegetation, which are mostly distributed within young secondary forest patches across Singapore. Young secondary forests are largely formed of exotic pioneer species and are more extensive than spontaneous vegetation and more evenly distributed across the island (Corlett, 1992). These areas typically have lower soil quality, primarily due to past intensive agriculture. Some of this agricultural land became urbanised after the Second World War, but much of it was left fallow and became this degraded forest type.

Spontaneous vegetation can provide ecosystem services to homebuyers, in the form of local climate regulation and provision of greenery. However, these areas are often not as accessible as managed and high conservation value vegetation. There is also a risk of human wildlife–conflict in these areas, albeit lower than in high conservation value vegetation. The lower levels of animal biodiversity in spontaneous vegetation are in part due to the limited number of forest plant species there (Corlett, 1992).

2.3. Hedonic Model Specification

The hedonic pricing method is commonly used to relate property selling price to neighbourhood, environmental and structural variables (Rosen, 1974). In the simplest case, ordinary least squares (OLS) regression can be used to explore relationships between explanatory variables and property price (Cho et al., 2008; Donovan and Butry, 2010; Irwin, 2002; Jim and Chen, 2009; Kong et al., 2007; Mahan et al., 2000; Morancho, 2003; Mueller and Loomis, 2008; Nicholls and Crompton, 2005; Poudyal et al., 2009; Tyrvainen, 1997; Tyrvainen and Miettinen, 2000). The OLS model is specified as follows:

$$SP = X\beta + \varepsilon \quad (1)$$

where SP is an $N \times 1$ column vector of property selling prices, X is an $N \times p$ matrix of the p explanatory variables, β is a $p \times 1$ column vector of regression coefficients, and ε is an $N \times 1$ column vector of model errors.

The simple OLS model ignores spatial autocorrelation, which can be important in hedonic pricing studies because regression residuals that are spatially closer to each other tend to be more similar (the first law of geography), invalidating the independence assumption of OLS and potentially biasing estimated effects sizes. Typical approaches for addressing spatial autocorrelation in hedonic pricing models include spatial lag, spatial error and spatial fixed effects models. Spatial error models assume that properties in similar locations or regions will have similar residual error. Spatial lag models assume that a property's residual error is influence by nearby properties' residual errors (Sander et al., 2010; Troy and Grove, 2008). Spatial fixed effects use dummy variables for the spatial location of properties as a normal explanatory variable, typically in an OLS regression (Fik et al., 2003). Other less common models for accounting for spatial autocorrelation include Generalised Additive Models (GAMs) (von Graevenitz and Panduro, 2015), and multilevel or hierarchical mixed-effects models (LMM) which have spatial random effects (Horsch and Lewis, 2009; Militino et al., 2004). Fixed effects variables in LMM are analogous to normal explanatory variables in an OLS regression. Random effects variables are factors with multiple levels. Each level is typically an observational unit where the error term is more likely to be non-independent. For example, in spatial LMM models different spatial scales containing non-independent observations are used, such as districts nested within regions nested within counties (Magezi, 2015).

In our Singapore case study, we expected apartments within a public housing town to be non-independent observations and thus to have correlated residuals. This could be driven by, e.g., the condition of apartments in the same block, the condition of nearby facilities, or other omitted variables. Therefore we fit our hedonic pricing model with an LMM in the R package lme4 (Bates et al., 2014, p. 4) (R Core Team, 2013), with nested random intercepts for public housing town, public housing street (spatially nested within town), and public housing block (spatially nested within street and within town) (Housing and Development Board, 2014). We also included an extra random effect for the transaction month, nested within the year of sale, to account for systematic variance across months. Our mixed-effects model has the following form:

$$SP = X\beta + Z\gamma + \varepsilon \quad (2)$$

where the variables and parameters are as in Eq. (1), and Z is the $N \times q$ design matrix for the q random effects, and γ is a $q \times 1$ vector of random effect coefficients.

2.3.1. Functional Form and Model Simplification

Variables with variance inflation factor (VIF) scores > 5 were removed from the maximal random effects model, to reduce the likelihood of multicollinearity in the model. This leads to the variable floor area (m^2) being dropped from subsequent models, which consequently reduced the VIF scores for apartment model and apartment type.

More flexible function forms, such as the box-cox power transformation are less likely to bias parameter estimates (Kuminoff et al., 2010). Therefore we searched for and applied the most appropriate lamda value for box-cox transformation of the dependent variable, for inclusion in the maximal model with random effects ($\lambda = -0.295$)We then ran the random effects model, and removed both fixed and random effects using a backwards stepwise approach aimed at minimising the Akaike Information Criterion (AIC). We then computed p-values for variables in the final model using Satterthwaite's approximations generated in the R package lmerTest (Kuznetsova et al., 2015).

2.3.2. Spatial Autocorrelation Testing

To test for spatial autocorrelation in the fitted models, we performed Moran's I test at multiple distance classes (Moran, 1950). The simple OLS model showed statistically significant evidence of spatial autocorrelation, whereas the LMM model did not (Fig. 3). We therefore used the LMM model in subsequent analyses.

3. Results

Our final model including fixed and random effects accounted for 97% of the variance in housing prices in Singapore; fixed effects alone accounted for 77% of this variance. Managed and high conservation value vegetation had statistically significant effects on property selling price, as did their interactions, while spontaneous vegetation only had a significant effect when included in interaction with managed vegetation (Table 2). The model estimated that the majority of public housing

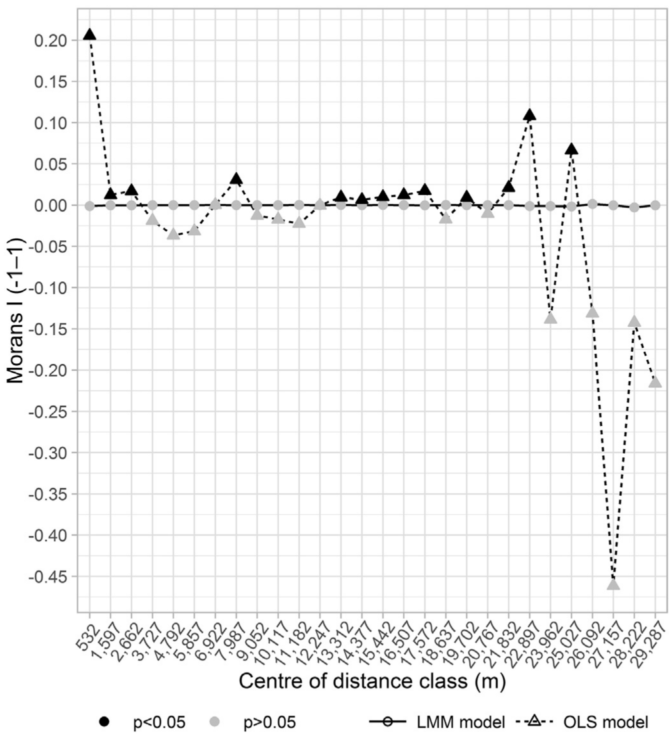

Fig. 3. Results of Moran's I test of model residuals for the ordinary least squares (OLS) model and the multilevel mixed effects (LMM) model. Box-cox transformation on dependent variable and fixed effects for each model are the same. Random effects for block number, nested within street nested within town, and for transaction month nested within year, were only included in the LMM model.

apartment selling prices in Singapore were positively affected by vegetation in their neighbourhood. However, different combinations of vegetation types had different effects on property selling price (Fig. 4). The estimated marginal effects of managed vegetation on property price were almost universally positive (98.1% of properties), and only negative when there was a lot of high conservation value vegetation in the vicinity. The effects of high conservation valuation vegetation were mostly negative (90.5%% of properties), with estimated positive effects only for properties without much managed vegetation nearby. The estimated marginal effects of spontaneous vegetation on property prices were mixed but mostly negative (62.7% of properties) and small. In fact, the total estimated utility value of vegetation across Singapore is entirely accounted for by managed vegetation: we estimate that managed vegetation was worth $197 million, but then the disamenity of the other vegetation types brought the total down slightly to $179 million. This is 3% of the total public housing property market value during the same period (S$5960 million) and an average of S$11,200 per apartment.

All non-vegetation explanatory variables were statistically significant aside from distance to top primary school, distance to coastline, and some levels of apartment model. The direction of the effects of explanatory variables on property selling prices were as expected (Table 2), with the exception of distance from bus interchange, which had a slight positive effect on property selling price. The most important explanatory variables in the model were apartment type, distance to Singapore's central area, apartment age and distance to nearest train station.

4. Discussion

We observed clear positive effects of managed vegetation on property prices in Singapore. These positive effects have a straightforward explanation: it includes managed parks and gardens that provide clear amenity value to nearby residents. In contrast, the effects of high conservation value vegetation were mostly negative, and the effects of spontaneous vegetation were slightly negative. The negative effects could be attributable to a lack of recreational facilities in these vegetation types and perceived threats from wild animals (see also below).

4.1. Effects of Vegetation

4.1.1. Managed Vegetation

The results suggest that managed vegetation is the vegetation type most valued by property purchasers. Homebuyers may be implicitly valuing the ecosystem services and recreational activities that this vegetation type provides. These include running, sports and children's activities, the aesthetic value of designed green landscapes, and the effect of shade and local climate regulation from trees. Our results corroborate those of previous research in Singapore, using case-study and survey-based techniques (Henderson, 2013; Yuen et al., 1996), and underscore the importance of managed parkland in the small island nation. The results also support previous research showing that Singapore residents want more “manicured” or managed landscapes then primary or secondary forests (Khew et al., 2014). Managed vegetation may also be more desirable than others due to the mere exposure effect, whereby individuals prefer this more “familiar” vegetation type in their neighbourhood (since Singapore's independence this has been the most common vegetation type in property neighbourhoods). Interestingly, even though our results suggest that property buyers in Singapore consider managed vegetation to be an amenity, a recent survey-based study in Singapore failed to find evidence of a strong effect of green space use and subjective wellbeing (Saw et al., 2015). More research on the benefits of green space in Singapore is needed to reconcile these results.

The positive impact of managed vegetation on property price found here is qualitatively similar to that found in previous studies conducted in Hong Kong and South China. Two studies in particular found that managed vegetation (parks) greatly increases property price and explains 10–15% of property value (Chan et al., 2008; Jim and Chen, 2010). The importance of managed vegetation in urban areas thus may be a general phenomenon across tropical Asia.

4.1.2. High Conservation Value Vegetation

High conservation value vegetation generally had negative effects on house prices; estimated effects were positive only for the 17.8% of properties with the least managed vegetation in the vicinity. We speculate that this is because homebuyers, in general, value having vegetation nearby but prefer managed areas. Only when there are few managed areas do homebuyers appreciate the presence of some conservation areas, and perhaps the associated boardwalk and nature trail facilities inside them, even though they may not perceive this vegetation as ideal. The benefits of high conservation value vegetation for this minority of homebuyers may also include greater abundance and diversity of wildlife, and the increased psychological benefits of more “natural” areas (Nilsson et al., 2011).

The majority of homebuyers who, our model estimates, see negative effects of high conservation as a disamenity may perceive risks from wild areas, such as dangerous wildlife (e.g., deadly snakes) or nuisance wildlife (e.g., long tailed macaques). Long-tailed macaques in particular are tolerant of human presence in Singapore and previous research has found their close proximity to humans has caused human–wildlife conflict in public housing towns. They are often found at the edge of nature reserves foraging for food from human sources (Sha et al., 2009a, 2009b; Yeo and Neo, 2010). Conservation areas may also be perceived as a source of mosquitoes making outdoor managed spaces less attractive. Mosquitoes spread diseases and dengue outbreaks have occurred across Singapore in recent years. Future research could overlay the predicted effect of high conservation status vegetation from this model with spatial data on areas where wildlife conflict is known to

Table 2
Box-cox transformed (λ = − 0.295) selected model marginal coefficient effects size estimates (n = 15,962). All variables were centred to their mean values. Categorical variables were dummy coded. Model A is the reference level for Apartment model. The lowest storey category (floors 01–05) was the reference level for storey categories. Not being in a highly ranked primary school catchment was the reference level for within catchment of top primary school. Degrees of freedom used in the calculation of p-values were calculated using Satterthwaite's Approximation. R^2 for fixed effects = 0.77 and for fixed and random effects = 0.97.

Variable	Estimate (S$/unit)	Standard error (S$/unit)	t-value	p-value
Intercept	3.31E + 00	7.14E-04	4640	< 0.001
Variables of interest				
Highcon vegetation (%)	−1.08E-04	4.11E-05	−2.64	0.008
Managed vegetation (%)	2.96E-05	9.30E-06	3.18	0.002
Spontaneous vegetation (%)	−2.26E-06	7.20E-06	−0.314	0.754
Managed vegetation:spontaneous vegetation (%)	1.09E-06	5.45E-07	2	0.045
Managed vegetation:highcon vegetation (%)	−1.75E-05	4.68E-06	−3.73	< 0.0.001
Control variables				
Freshwater (%)	6.11E-05	1.24E-05	4.92	< 0.0.001
Park facilities richness	3.17E-05	1.55E-05	2.04	0.041
Within catchment of top primary school (1000 m)	1.29E-04	1.08E-04	1.2	0.231
Within catchment of top primary school (2000 m)	1.13E-04	8.31E-05	1.36	0.175
Distance to central area (m)	−4.44E-07	4.97E-08	−8.93	< 0.0.001
Distance to nearest cooked food centre (m)	−1.91E-07	7.89E-08	−2.42	0.016
Distance to nearest train station (m)	−1.75E-06	1.01E-07	−17.4	< 0.0.001
Distance to bus interchange (m)	4.25E-07	1.02E-07	4.16	< 0.0.001
Distance to nearest major shopping mall (m)	−4.98E-07	1.05E-07	−4.75	< 0.0.001
Distance to nearest motorway (m)	1.89E-07	7.95E-08	2.38	0.017
Distance to coastline (m)	−1.23E-07	6.78E-08	−1.81	0.071
Time since lease commencement (age) (years)	−1.34E-04	3.87E-06	−34.6	< 0.0.001
Apartment type - 1 Room	−1.77E-02	9.33E-04	−19	< 0.0.001
Apartment type - 2 Room	−1.26E-02	1.13E-04	−111	< 0.0.001
Apartment type - 3 Room	−6.10E-03	3.50E-05	−174	< 0.0.001
Apartment type - 5 Room	4.26E-03	5.09E-05	83.8	< 0.0.001
Apartment type - Executive	6.90E-03	1.18E-04	58.6	< 0.0.001
Storey category - 06 to 10	7.78E-04	2.17E-05	35.8	< 0.0.001
Storey category - 11 to 15	1.23E-03	2.72E-05	45.1	< 0.0.001
Storey category - 16 to 20	1.82E-03	5.16E-05	35.3	< 0.0.001
Storey category - 21 to 25	2.34E-03	8.59E-05	27.2	< 0.0.001
Storey category - 26 to 30	2.66E-03	1.38E-04	19.3	< 0.0.001
Storey category - 31 to 35	2.63E-03	2.53E-04	10.4	< 0.0.001
Storey category - 36 to 40	2.70E-03	2.85E-04	9.49	< 0.0.001
Apartment model - Adjoined flat	3.39E-03	2.46E-04	13.7	< 0.0.001
Apartment model - Premium Maisonette	9.32E-04	1.35E-04	6.89	< 0.0.001
Apartment model - DBSS	9.46E-04	1.63E-03	0.581	0.561
Apartment model - Model A-Maisonette	−1.19E-03	5.67E-05	−21	< 0.0.001
Apartment model - Maisonette	1.06E-03	1.45E-04	7.32	< 0.0.001
Apartment model - Standard	2.35E-03	3.88E-04	6.05	< 0.0.001
Apartment model - Apartment	−1.05E-03	1.31E-04	−8.01	< 0.0.001
Apartment model - Premium Apartment	−9.98E-04	6.20E-05	−16.1	< 0.0.001
Apartment model - Model A2	1.22E-04	1.06E-04	1.15	0.249
Apartment model - Simplified	3.12E-03	1.23E-03	2.53	0.011
Apartment model - New Generation	−2.78E-03	6.63E-05	−41.9	< 0.0.001
Apartment model - Improved	−5.98E-04	1.32E-04	−4.53	< 0.0.001

have occurred in Singapore. The analysis would then answer the question of whether hotspots of actual human–wildlife conflict have caused a drop in selling price. It is also possible that the conservation value of this vegetation may not be fully understood by homebuyers: previous research in Singapore has revealed a misconception among homebuyers that managed vegetation is equivalent to natural vegetation in terms of its importance for nature preservation, something respondents stated as being important (Khew et al., 2014).

4.1.3. Spontaneous Vegetation

The lower value attached to spontaneous vegetation by homebuyers may be due to the lower variety of recreational activities available when compared to the other two vegetation types. High conservation value areas often have nature trails and walks; and managed vegetation is often designed to meet expectations of landscape attractiveness in Singapore and is much more accessible. In a similar way to having high conservation value vegetation, the negative effect may be driven by residents fearing the presence of wild animals such as snakes and macaques. Previous studies have found that these animals are perceived as either dangerous or a nuisance in these areas (Sha et al., 2009a; Yeo and Neo, 2010).

4.2. Other Explanatory Variables

4.2.1. Apartment Structural Characteristics

This study corroborates previous hedonic pricing research in Singapore (Sue and Wong, 2010), Asia, and the world, by suggesting that structural characteristics (specifically age and floor area of a unit) are the most important determinants of property price. The strong effect size for apartment type (collinear with floor area) matches the positive effect of floor area in another previous Singapore-based study with condominium selling price as a dependent variable (Andersson, 2000). For apartment storey preference, however, we found a different result from previous research in Singapore. Whereas a previous survey-based study (Yuen, 2005) found that respondents prefer mid-level apartments, our hedonic pricing analysis suggested people prefer high-level apartments. The results from our research may be more accurate as stated preferences from surveys are subject to biases from consequentiality and incentive compatibility, and therefore do not always match revealed consumer actions modelled in hedonic pricing studies

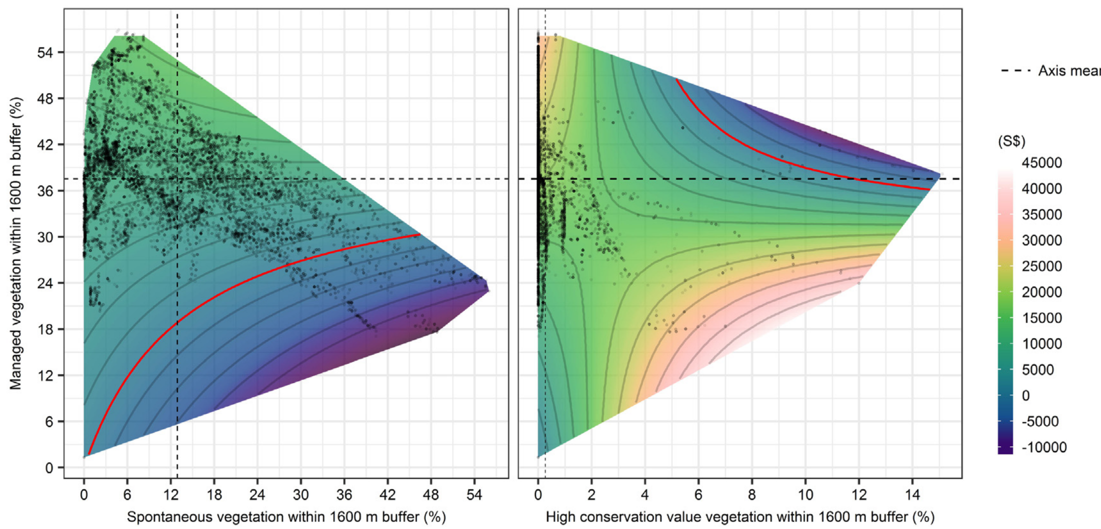

Fig. 4. Estimated effect of box-cox back-transformed vegetation variables on public housing apartment selling prices in Singapore with all other model variables set to their means. The coloured areas correspond to a convex hull covering the range of observed data. Dashed lines show the mean of each axis variable. Solid black curves show price isoclines, i.e., curves along which the effect of the plotted vegetation variables on apartment price is constant. Each red curve shows combinations of the vegetation types on the two axes whose estimated effect on property value is equivalent to having 0% of the two vegetation types, with the third vegetation type held at its mean. Points show each public housing apartment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Loomis, 2014).

4.2.2. Neighbourhood

Among all neighbourhood variables, distance to the Singapore city centre was found to have the largest effect on house prices, consistent with previous research (Yuen, 2005). Also consistent with previous research in Singapore (Sue and Wong, 2010; Yuen, 2005), we found that distance to train stations had a large effect size, suggesting that consumers in Singapore will pay a premium to be located close to the train network, the most commonly used local transport system (Jim and Chen, 2010). We also found that distance to nearest cooked food centre had a strong effect size, suggesting that property purchasers within Singapore value ease of access to these culinary and cultural centres. The richness of park facilities in a neighbourhood was found to have a positive and significant effect on selling prices. Again this relates to previous research showing that individuals prefer neighbourhoods to have managed parks and associated facilities (Henderson, 2013; Yuen et al., 1996). Previous research in Singapore (Sue and Wong, 2010) has found a positive effect on property prices of being close to top primary schools; we also found a slight positive effect, although it was not statistically significant. Unexpectedly, being located away from a bus interchange had a positive effect on property selling prices. This may be due to increased pollution caused by a large cluster of diesel machines being a larger disamenity then having the improved accessibility they offer.

4.3. Recommendations

Among the world's nations, Singapore has the third highest population density with 7710 individuals per km^2 as of 2013 (The World Bank, 2013). Land is therefore scarce and must be allocated efficiently if Singapore is to thrive. Competing land uses include urban development and conservation of forest and other habitats. Although Singapore is small and already highly developed, there exist some species (such as the colugo, hornbill and banded-leaf monkey) that have a high conservation value within nature reserves. Several are threatened not just nationally but globally (e.g., Sunda Pangolin, Johnson's freshwater crab) and so protection of their habitats is imperative.

Our analysis shows that when mixed with the most influential vegetation type (managed vegetation), high conservation value vegetation has negative effect on house prices in Singapore. Therefore, we recommend that future public housing towns be constructed at least a couple of kilometres away from high conservation status vegetation areas to reconcile the twin goals of maximising value to homebuyers and conserving Singapore's remaining biodiversity.

There does appear to be a synergy between managed vegetation and urban development: our results provide new evidence that government initiatives to developing Singapore into a “city in a garden” with a “lush green experience” will benefit Singapore's residents (Henderson, 2013). One of these initiatives has been government-sponsored tree planting, which has been used since 1967 to provide ecosystem services of heat reduction and aesthetic enjoyment (Lye, 2008). Based on the high value of managed vegetation identified here, we recommend that future public housing developments continue to provide outdoor managed green recreational space for residents, as has been the case with new local developments such as Punggol eco-town (HDB InfoWEB, 2014). However, more research should be conducted on increasing the habitat connectivity in managed to semi-managed vegetation which could help support biodiversity and property value appreciation, by combining some of the benefits of both these vegetation types. In future research, managed vegetation should also be placed into more discrete categories to further disentangle which kind of managed green space is more economically valuable.

We also recommend policies to encourage public awareness of ecosystem services, which will ensure that vegetated land is not undervalued by property purchasers. Although our analysis suggests that high conservation status vegetation in particular is not valued by property purchasers, this may change in the future if awareness of the benefits of conservation areas rises.

4.4. General Limitations

The hedonic pricing method can only create a partial valuation of Singapore's vegetation, i.e., the value of ecosystem services provided to homebuyers. Other ecosystem services provided by vegetation such as carbon sequestration, recreational use by individuals who do not live close by, existence values and watershed services, are ignored in analyses based on house prices but should be included in any holistic assessment of vegetation value. Similarly, the hedonic pricing method does not take into consideration the non-substitutable benefits, the loss of which would be irreversible on policy timescales if very old (primary forest, old secondary forest) vegetation patches were removed. These factors should be considered in land-use decisions.

Even among the ecosystem services that do benefit homebuyers, our method provides a lower bound on the value provided by vegetation because homebuyers may lack awareness of ecosystem services that benefit them directly. One particularly relevant example is the increased cost of air conditioned cooling caused by a reduction in vegetation cover in a neighbourhood. Again, the solution is to run public awareness campaigns.

Another limitation of this study is that it considers only the value of vegetation to consumers in Singapore's public housing market. Conducting a valuation of the private housing market could better assess whether the quantity of different types of vegetation in a neighbourhood is a luxury good, as individuals buying private housing are likely to have more disposable income then those buying public housing apartments.

Lastly as is inherent to all statistical modelling methods (including hedonic pricing), omitted variables can bias the effects sizes and errors of model variables, should they be collinear. One particular limitation of the research was the absence of land-use zoning data. This information is not publically available in Singapore and therefore we could not use the data in our analysis, which may have influenced the effect of other spatial variables. However, by addressing spatial autocorrelation using a mixed-effects model, we have attempted to minimise this bias. Furthermore, we have included a number of variables that explain zoning patterns, such as distances to the central area, nearby shopping malls and cooked food centres. Another technical limitation of our study is the size of the vegetation classification pixels (10 m × 10 m). Because tree canopies can be smaller than this, our methods underestimate the value of smaller managed vegetation patches such as isolated trees and smaller shrubs.

5. Conclusions

We have estimated the economic value homebuyers place on vegetation using the hedonic pricing method in an attempt to determine how the demand for vegetation in a tropical developed city can differ from other ecozones, and provide insights into future planning of tropical cities as they develop across the world. The results show that during the 13 month period 3% of the value of all public housing properties sold on the resale market was attributed to neighbourhood vegetation (S$179 million). However, different combinations of vegetation types have different effects and importantly, the expected positive effect of high conservation value forest on housing prices was not found. Therefore, Singapore cannot rely on homebuyer preferences to encourage forest conservation. Similarly, homebuyers place a low value on spontaneous vegetation. For managed vegetation, such as parks and street trees, the prospects are brighter: homebuyers apparently attach a premium to such vegetation, a result which should encourage the creation of more green space overall in Singapore. In order to reconcile the protection of high conservation status areas and maximise utility to homebuyers, new public towns should be located away from high conservation status areas, and should continue to provide high quantities of managed vegetation.

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Appendix A. Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2018.03.012.

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