Ecosystems and the spatial morphology of urban residential property value: a multi-scale examination in Finland

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Ecosystems and the spatial morphology of urban residential property value: a multi-scale examination in Finland

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Abstract: This paper provides evidence for the spatial effects of ecosystems on value formation and differentiation in the urban residential property market. An amenity-based location theory is used in conjunction with hedonic function estimations from the Finnish cities of Helsinki, Espoo and Pori to distinguish between two different ways that ecosystems influence market value: a citywide spatial equilibrium and an additional layer of micro-scale fragmentation. The effect across spatial scales is complemented by two forms of distance decay: a logarithmic decay and a linear dependence on distance to the city centre. Lastly, the estimated marginal values exhibit noticeable temporal variation, even after using de-trended prices. The results highlight the structural role of the ecosystem in the housing market and suggest that the effect of ecosystem services is clearly conditional on the spatiotemporal context, with a visible degree of selectivity to specific services. It is also evident that a realistic understanding of the role of the ecosystem on property value must assess its effects as spatial bundles of services rather than singular flows of one service at a time.

Keywords: urban ecosystems, spatial effects, residential property value

1 Introduction

A meaningful incorporation of the ecosystem and its services in urban adaptation and sustainability analysis must consider the details of its role in urban welfare. To this end, the differentiation of residential property value is an important indicator because it largely reflects the morphology of urbanization benefits for residents. Linking the ecosystem to property prices is thus one way to understand its structural role in an urbanized setting. De Groot et al (2002) and Bateman et al (2010) provide an enumeration of methodologies for linking the ecosystem to economic value, with the hedonic approach being the most relevant for the housing market. In hedonic price theory, housing is viewed as a composite commodity that consists of a bundle of n attributes. This modifies the housing buyer's traditional utility function from $\mathrm{u}(c, q)$ to $\mathrm{u}(c, a_1, a_2, \ldots, a_n)$, with a_i an element of the dwelling's attribute bundle, q housing consumption and c the sustenance or "bread" consumption (Brueckner, 2011, p.117). By estimating the market price of this commodity as a function of its attributes, it is possible to derive an implicit marginal value for each of the attributes (e.g. Rosen, 1978; Dubin, 1988; Sheppard, 1999).[1]

The aim of this study is to analyse the structural role of ecosystems in residential property value formation and differentiation at multiple spatial scales, while controlling for other important factors. The study estimates the marginal effects of selected ecosystems on property value through hedonic functions. However, the hedonic viewpoint contains key uncertainties with respect to what price differentiation mechanisms are reflected by the estimated marginal values. This article suggests that a city-wide spatial equilibrium and micro-scale demand and supply must be considered concurrently when assessing the effects of ecosystems, and this implies the use of multiple spatial scales. For this reason, an amenity-based residential location theory (Brueckner et al, 1999) is utilized as a necessary theoretical amendment to the empirical merits of hedonic price theory. The text will refer to the former

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[1] The estimated coefficients are interpreted as marginal values or effects. They can be further treated as functions of household characteristics, retrieving the demand for amenities (Brueckner, 2011, pp.117-118; Quigley, 1982). Household characteristics are important also for the main alternative of hedonic regressions, the discrete choice modelling of residential location (e.g. McFadden, 1977; Ellikson, 1981; Cropper et al, 1993; Sheppard, 1999); such data were not available in this study.

as the citywide mechanism or equilibrium and to the latter as the micro-scale mechanism of fragmentation or differentiation of value.

The spatial equilibrium of residential location and the resulting value differentiation across the city (von Thünen, 1826; Alonso, 1964; Mills, 1967; Muth, 1969) on one side, and the local mechanism of micro-scale demand and supply that results to further value fragmentation on the other side, are two distinct price differentiation mechanisms. Considering the broader urban economic system, these mechanisms are concurrently reflected by the implicit values of man-made or natural elements in the built environment, if observed market prices are used for the estimation of those values. Moreover, the valuated flow of ecosystem services suggested in environmental economics literature is in fact a spatial flow, since the urban economy is essentially a spatial game of finite resources and land use competition. Not accounting for these details hinders the correct assessment of the impacts of ecological change or its use as an adaptation and sustainability tool in the city. The present study has employed the amenity-based residential location theory of Brueckner et al (1999) that, together with hedonic price theory, establishes theoretical expectations for the structural role of the ecosystem in the differentiation of property value.

The next section proposes the implications that follow from the consideration of an amenity-based location model in conjunction with hedonic theory with respect to the role of the ecosystem in value differentiation. Section three outlines the empirical methods and data used in the study. Section four provides empirical results and a discussion in support of the theoretical propositions of the first and second sections. The fifth section offers concluding remarks about the studied spatial effects. In addition, the conclusion links the presented research to a broader context of urban adaptation and sustainability.

2 Amenities as a structural element in value differentiation

Hedonic price theory captures well aggregate supply and demand in the property market but does not account for the idiosyncrasies of each city or other value formation mechanisms that might be operating concurrently. Although comprehensive econometric procedures are suggested for arriving at the best hedonic function specification (e.g. Sheppard, 1999, pp.1613-1619; LeSage and Pace, 2009, pp.155-187), this in a sense turns the procedure on its head, overlooking the merits of theoretical urban modelling. The Alonso-Mills-Muth family of models does place theoretical expectations for the morphology of value in the city, but is best used to describe the North American monocentric city of the past centuries. To this end, the location model of Brueckner et al (1999) has two advantages. Firstly, it is especially fit for the Nordic urban morphology from which this study takes its empirical evidence. Secondly, it considers the spatial morphology of amenities as the main determinant of the spatial equilibrium, with the ecosystem being one of the three accounted amenity types. This enables to first lay out theoretical expectations for the structural role of the ecosystem on price formation that complements the numerical merits of the hedonic approach.

Natural and historical amenities are assumed exogenous to the bid-rent function, while modern cultural amenities are seen as endogenous consequents in locations where wealthy households locate. Dwelling consumers are characterized by the utility function $\mathrm{u}(y - tx - pq, q, a)$, where y is income, t commuting cost, x distance from the central business district (CBD), p price per housing unit, q housing consumption and a amenities. Variables p and q are functions of x, so that $p(x)$ is a "bid-price" function with two important components: the t/q ratio of the Alonso-Mills-Muth models plus an amenity-dependent component. The rate of change $\mathrm{d}p/\mathrm{d}x$ is the function $p'(x) = -[t/q(x)] + [\{v^{\mathrm{a}}[y - tx, p(x), a(x)]\}/q(x)]a'(x)$, where v^{a} is the marginal valuation of amenities after optimal adjustment of housing consumption. As Brueckner et al. note, most models unjustly assume $v^{\mathrm{a}} \equiv 0$ and overemphasize the role of $t/q(x)$ (1999, p.96). In addition, evidence is cited from Wheaton (1977) that $t/q(x)$ does not vary sufficiently across cities to justify its frequent use as the crucial location determinant (1999, p.93). The second constituent of $p'(x)$ is an important proposition when trying to understand possible mechanisms by which the environment forms and differentiates real estate values, especially in light of the major ecological and climate changes the cities have to adapt to. The environment is internalized as a structural element of the urban system. From this point on, the key assumptions are that the marginal valuation of amenities rises sharply with income, and that the wealthy are characterized by a high opportunity cost of time (Brueckner et al, 1999, pp. 93, 96).

While insignificant variation in amenities across the city makes the location of the wealthy dependent mainly on transportation cost and dwelling type preferences, introducing a realistic spatial variation in exogenous amenities produces value morphologies that are consistent with many European cities. The wealthy will outbid the rest in the city centre, if it contains a sufficiently maintained historical built environment and “unique” natural amenities that stand out in the overall distribution of nature across the city. Urban blue in the form of a coastline or attractive river banks are such cases. Moreover, even in a homogenous distribution of green across the city, it is reasonable to assume that urban green spaces at the centre will have an exogenous effect on location. Firstly, they are oftentimes combined with historical amenities (e.g. a park next to a museum) or are valued design elements themselves (e.g. through their architectural details). Secondly—and more pragmatically—they alleviate negative externalities such as air, noise and visual pollution, making the otherwise beneficial central locations more favourable (e.g. Givoni, 1998; Tyrväinen, 1997; Tyrväinen and Miettinen, 2000; Hauru et al, 2012).

Modern amenities as endogenous factors suggest that contemporary amenities such as restaurants, cinemas and shopping or art districts tend to follow high concentrations of wealthy dwellers. This establishes a certain neighbourhood spirit, culture or prestige. The most obvious effect of this tendency is that it reinforces the location pattern described in the previous paragraph; that is, historical and natural amenities in the city centre will attract the wealthy and this will further establish modern amenities in a positive loop-like feedback. An equally interesting effect of endogenous amenities stems from the fact that there will always be indeterminacy in additional favourable locations for the wealthy, beyond the obvious city centre. The value of such minor cores will be then reinforced by the emergence of modern amenities, inducing a multicentric morphology of high-value clusters.

It is reasonable to assume that the theorized location equilibrium will be mirrored by an empirically observed morphology of residential values; the aggregate demand of the wealthy for a particular location will drive its average value up. As already mentioned, this general price differentiation is followed by a subsequent fragmentation due to quality variation on a dwelling and/or small neighbourhood basis; this is well explained by hedonic price theory. Urban ecosystems naturally enter both differentiation layers, and this means that hedonic functions will estimate non-constant implicit values that reflect both city-wide and micro-scale mechanisms. Thus, the following theoretical expectations can be put forth:

Firstly, a varying spatial aggregation scheme will separate the two differentiation mechanisms: aggregate (“coarse”) scales will reflect what ecosystem aspects are relevant to the overall spatial equilibrium, whereas disaggregate estimations will indicate those additional aspects that are responsible for the micro-scale fragmentation of value. Secondly, since the marginal valuation of amenities is a function of location, the estimated hedonic functions are expected to reflect this feature. The implicit value of amenity a_i will be non-constant, dependent on and variable with location. Thirdly, spatially weighted measures of price per unit of housing consumption are likely to have strong empirical relevance, as they are good proxies for the endogenous component of the utilized amenity theory.

3 Data and methods

The analysis has used property transaction data from Helsinki, Espoo and Pori. Helsinki (≈ 535,384 inhabitants as of 31.12.2011, 21,655 hectares) is the capital of Finland and Espoo (≈ 252,439 inhabitants, 33,219 ha) is one of its adjoining municipalities. Both cities are part of the broader capital region at the southern tip of Finland, on the coast of the Baltic Sea, with a population size of about 1,360,000. Pori (≈ 83,133 inhabitants, 88,135 ha) is a river town in the southwest of Finland. In terms of population rank size, Helsinki and Espoo hold the 1st and 2nd ranks, while Pori the 11th (Statistics Finland, 2013).

The transaction data record the selling price, debt component[2] and technical maintenance cost of the dwelling, together with its postal address and several structural characteristics of the property.[3] All monetary variables (price, debt, maintenance cost) were adjusted for inflation with 2011 as the reference year. The original data were enhanced in two ways. Firstly, based on their postal address and a geo-referencing operation, the geographical coordinates of the observations were retrieved in order to enable spatial analysis. Secondly, several ecological variables were added to the original observations in order to produce what Dubin (1988) describes as the structural, locational and neighbourhood characteristics of the dwelling, suitable for the estimation of hedonic functions. The final selection of variables is presented in Table 1. For the cases of Helsinki and Espoo, CBD refers to the central business district of Helsinki.

TABLE 1: THE VARIABLES OF THE ANALYSIS

Variable	Description	Unit
PRICE	Selling price per m^2, adjusted for inflation (ref. year 2011)	€ thousand per m^2
LAMBDA	Spatial error coefficient (λ)	€ thousand per m^2
DEBT	Debt of the housing committee for large repairs, adjusted for inflation	€ thousand per m^2
MAINT	Technical maintenance cost, adjusted for inflation	€ thousand per m^2
FLOORSP	Floor-space	m^2
ROOMS	Rooms, excluding kitchen	multinomial (1–9)
FLOOR	The floor on which the apartment property is situated	multinomial (1–9)
AGE	Difference between selling and construction year	years
BADCND	Bad condition	binomial (1/0)
AVGCND	Average condition	binomial (1/0)
CBD	Distance to Helsinki's central business district	metres
SEA	Distance to the coastline	metres
LAKE	Distance to the nearest lake	metres
LAKEVIC	In the immediate vicinity of a lake (radius varies slightly by sample)	binomial (1/0)
RIVER	Distance to the river bank	metres
PARK	Distance to the nearest park	metres
FOREST	Distance to the nearest forested area	metres
PCTFORE	Portion of grid cell that is forested	%
SPREC	Distance to the nearest sports/recreation area	metres
PARKDENS	Park density	facilities per km^2
SPRECDENS	Sports/recreation areas density	facilities per km^2
OWNPLOT	Whether the property has a privately owned plot	binomial (1/0)
ONSALE	Amount of time that the property was on sale in the market	days
YEAR	Transaction year dummy; 0 is assigned to the earliest year	bi- or multinomial
DWELTP	Dwelling type (1: apartment, 2: row house, 3: single family house)	multinomial (1–3)

[2] Debt arises mostly in units under a common roof, *e.g.* the units of an apartment building or row houses under a common roof. Such properties frequently establish a managing committee. Large maintenance expenses such as the replacement of the roof are undertaken by the committee and financed by a loan. The loan is then distributed to each property, usually according to its size, and the debt component of a property reflects this obligation. It bounds the property rather than the owner, and passes from one owner to the next when the property is sold.

[3] These data are voluntarily collected by a consortium of Finnish real estate brokers and the dataset is maintained by the Technical Research Institute of Finland (VTT). As not all real estate agencies participate, the dataset represents a sample (albeit rather large) of the total volume of transactions.

The discussion in the preceding sections motivates a spatial approach. Hedonic functions were repeatedly estimated for neighbourhood-level (grids of spatially aggregated observations) and dwelling-level (disaggregate) data. The neighbourhood-level data were produced by aggregating the observations into four separate hexagonal lattices with diameters of 5778, 2207, 521 and 199 metres. The dwelling-level data refer to the original observation points and did not involve a spatial aggregation scheme. The four non-rounded dimensions of the hexagons represent non-successive points selected from an exponential spatial scale sampling scheme ($scale_{n+1} = scale_n * e^{0.4812}$), aimed at grasping how price forms at different spatial scales, from the city-wide level down to the local micro-scale. Aggregate observations contain transactions of all housing types (i.e. apartments, row houses, single family dwellings) for the period between 2000 and 2011. Disaggregate observations represent apartments only, and were split in annual or biannual subsamples to maintain an adequate sample size. Regardless of the aggregation scheme, the unit of the dependent variable and estimated marginal effects remains the price per square metre for one property; at the disaggregate level it reflects the value of each property, whereas at the aggregate levels it refers to the average expected value of a property belonging to a grid cell. The multiple aggregations should not be confused with the modifiable areal unit problem or the ecological fallacy issue (Viegas et al, 2009; Anselin, 2002). The aggregations are based on point observations and inferences made refer to the corresponding spatial units of neighbourhoods and city districts. Similarly, inferences about individual properties are based on disaggregate property transactions.

Explicit assumptions about spatial interaction were made, by letting the first-order von Neumann neighbourhood determine the construction of spatial weights. For a hexagon, this translates to its first ring of neighbours. For the disaggregate data, the Thiessen polygons of the points were used to extract contiguity. Spatial autoregressive models (SAR) were used, which implies that any identified spatial externalities are global (Anselin, 2003). However, the particular nature of the externalities has been data-driven. The general SAR function $\boldsymbol{y} = \rho\mathbf{W}\boldsymbol{y} + \beta\mathbf{X} + \lambda\mathbf{W}\boldsymbol{u} + \boldsymbol{e}$ (1) was assumed, where $\boldsymbol{y}$ is PRICE, $\mathbf{W}$ a spatial weights matrix, $\mathbf{W}\boldsymbol{y}$ a spatially lagged form of PRICE, $\mathbf{X}$ a matrix of independent variables, $\mathbf{W}\boldsymbol{u}$ a spatially autocorrelated error term isolating unobservable spatial effects, $\boldsymbol{e}$ an i.i.d. error term, and ρ, β, λ coefficients. Lagrange Multiplier (LM) tests in a maximum likelihood framework were used for simplifying (1) and resulted in all cases in the spatial error specification of the form $\boldsymbol{y} = \beta\mathbf{X} + \lambda\mathbf{W}\boldsymbol{u} + \boldsymbol{e}$. The foundations of these models are outlined, among others, in Anselin (1988), Anselin (2003), LeSage and Pace (2009), Anselin et al (2010), Piras (2010) and Gerkman (2011). The analysis has used the *spdep* module (Bivand et al, 2012) of R statistical software (R core team, 2012) and GeoDa spatial data analysis software (Anselin et al, 2005).

4 Empirical results and discussion

The first expectation set forth in the second section is that a multiple spatial aggregation framework will be able to detect the ecosystem's separate contributions to city-wide and micro-scale price differentiation mechanisms. Table 2 provides the hedonic estimations across different spatial scales for the Helsinki-Espoo urban area, and Figure 1 shows the discussed scaling structure.

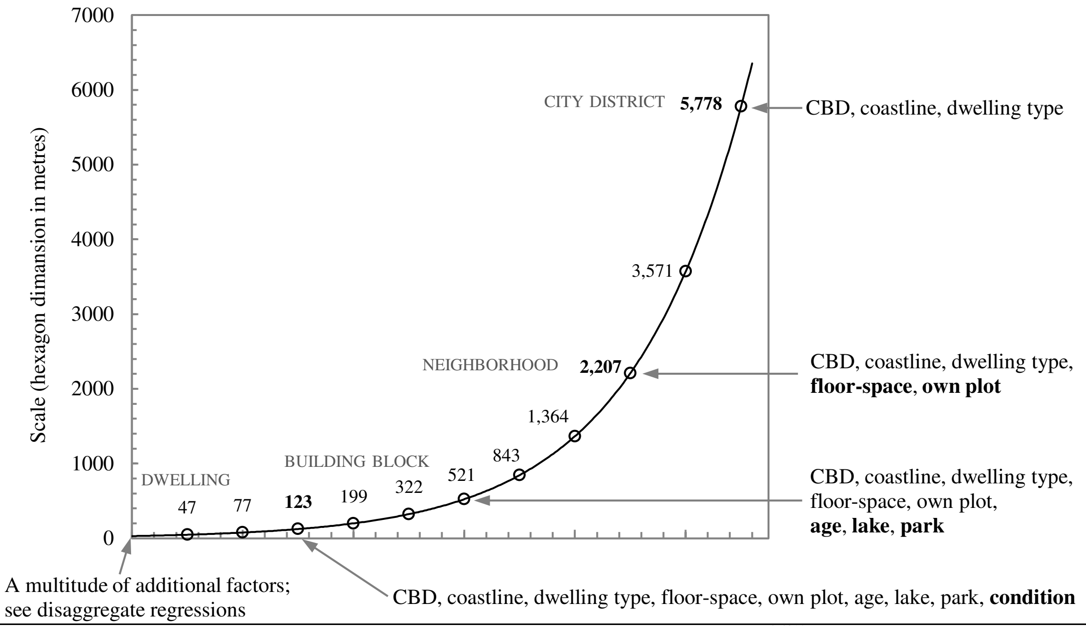
A structure of price differentiation factors is evident with respect to whether the price formation is examined via a few large districts or many small neighbourhoods. At the coarser spatial scale (5778 metres), 82 per cent of price variation is explained by proximity to the CBD and the coastline, and by the type of dwelling. As the scale becomes finer, additional factors—including additional ecosystems—enter the price differentiation process, while the unexplained variation increases. Most notably, while the coastline remains a strong determinant of price formation, a number of urban green and blue elements enter the differentiation process at relatively fine scales, starting at the 521-metre neighbourhood. The dominance of the CBD and coastline across spatial scales indicates their role as city-wide residential location determinants, in line with the theoretical expectation of Brueckner et al. (1999). Thus, the coastline can be considered as the most important environmental amenity for the Helsinki-Espoo urban area, whereas Helsinki's CBD (a historical district with a rich portfolio of architecture, urban design and green spaces) fits well in the role of historical amenity; the two fulfil the range of exogenous determinants anticipated by the utilized amenity theory.

TABLE 2: HEDONIC ESTIMATIONS ACROSS AGGREGATE SCALES, HELSINKI-ESPOO URBAN AREA

Scale:	5778m		2207m		521m		199m	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Intercept	11.096	.000	9.767	.000	10.216	.000	10.633	.000
log [CBD]	–.859	.000	– .736	.000	– .665	.000	– .719	.000
log [SEA]	–.198	.000	– .313	.000	– .235	.000	– .212	.000
DWELTP	.657	.000	.665	.000	.471	.000	.368	.000
FLOORSP			– .003	.022	– .004	.000	– .004	.000
OWNPLOT			.647	.000	.405	.000	.289	.000
YEAR			.115	.000	.070	.000	.088	.000
LAMBDA (λ)			.339	.009	.466	.000	.448	.000
AGE					– .015	.000	– .015	.000
$[AGE]^2$					1.649e-04	.000	1.66e-04	.000
LAKE					– 9.022e-05	.003	– 6.419e-05	.001
log [PARK]					– .019	.003	– .033	.013
BADCND							– .235	.000
AVGCND							– .223	.000
PCTFORE							– .087	.063
PARKDENS							– .022	.135
SPRECDENS							– .005	.003
Adjusted R^2	.82		–		–		–	
Negelkerke R^2	–		.7		.67		.63	
N (of hexagons)	29		136		1149		3788	
Model type	OLS		Spatial error		Spatial error		Spatial error	

Notes: 1. The reported coefficients are interpreted as marginal effects and correspond to € thousand per m^2. 2. The observations (hexagons) are not a sample but artificial city regions that physically exhaust space.

FIGURE 1: PRICE DIFFERENTIATION FACTORS IN THE COMBINED HELSINKI-ESPOO AREA



Note: New factors at each scale shown in bold; scale ε increases exponentially: $\varepsilon_{n+1} = \varepsilon_n * e^{0.4812}$.

Regressions for the city of Pori yielded a comparable but more ambiguous hierarchy. The CBD dominates across scales together with the age and condition of the housing stock. Ecosystems become relevant at the 521-metre scale, represented by lakes and forested areas. The river's influence is clear only at 199 metres, while the coastline only at 2207 metres. Compared to the Helsinki-Espoo area, these differences may be partly due to a rather uniform spatial distribution of ecological amenities, in combination with the city's small size that limits serious negative externalities inside the CBD. Both aspects render the ecosystem relevant only in micro-scale differentiation, confirmed by the disaggregate estimations for Pori.

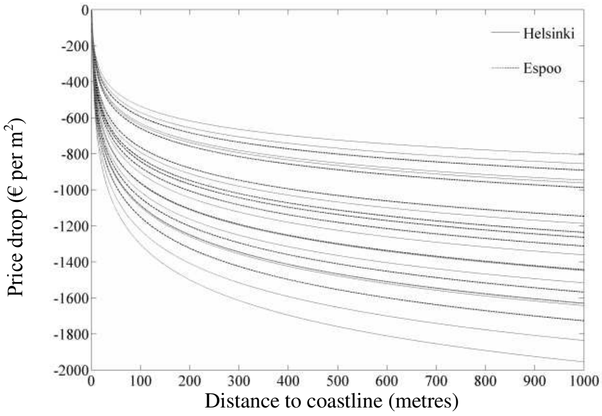
The estimations at the disaggregate scale have been able to confirm the assumed micro-scale differentiation mechanism. Tables 3a, 3b and 3c report the hedonic estimations for a large sample of apartments in Helsinki, Espoo and Pori between 2000 and 2011. As expected, property-specific attributes become evident differentiation factors at this scale, which contrasts to the dominance of neighbourhood-relevant factors in the aggregate models. However, it is important to notice that the city-wide factors are present at this scale as well, since the two price differentiation mechanisms co-differentiate value. A few price differentiation factors are common regardless of the city, most notably the distance of a property to the CBD and age- or condition-related attributes. Ecosystems appear as universally important in the price differentiation process, contrary to the conventional intuition that the influence of ecosystems is too weak to be detected.

Nevertheless, the kind of ecosystem detectable in price formation varies significantly between the three cities. Diversity is observed also in the functional form of the marginal effects. This naturally depends on what is available in each urban area and how it is incorporated in the built environment, but there is also evidence that residents are selective with respect to what type of ecosystem services they favour. The most vivid evidence for this is the fact that while it has been possible to model the marginal effect of urban green in all three cities, the mix of specific kinds of urban green—therefore, the mix of received ecosystem services—is different for each city. Another evidence for the selectivity towards the mix of preferred ecosystem services is the term FORES50*RIVER in the case of Pori; it indicates that proximity to the river bank increases price, but only for properties within 50 metres from a forested area. In other words, it is a specific mix of ecosystem services that influences value formation, a fact that casts doubt to the usefulness of dissecting ecosystem services beyond a certain limit, as they most often work together in complex ecological land use patches.

The logarithmic distance decay suggests that the positive effect of some ecosystems on residential property value concerns the dwellings in close proximity to the ecosystem. The marginal effect falls sharply when moving away from the ecosystem. Moreover, explorative spatial autocorrelation analysis (Moran, 1950) suggests that the price premium spills over to the properties that are neighbouring those in direct proximity to the ecosystem in question. Thus, the logarithmic distance decay likely encapsulates both pure and spill-over effects. For the case of Espoo and Helsinki, the coastline is the major ecosystem exhibiting logarithmic distance decay of marginal effects (log [SEA]). Figure 2a demonstrates this behaviour by plotting the estimated price drops in Espoo and Helsinki when moving away from the coastline. The strongest logarithmic decay is exhibited by proximity to the CBD.

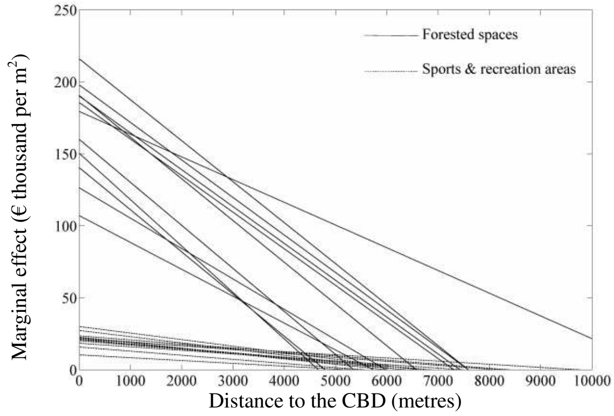
On the other hand, the interaction terms CBD*FOREST and CBD*SPRECDENS in the case of Helsinki's apartments suggest that other ecosystem services exhibit a maximum marginal value at the CBD, with the effect decaying when moving away from that location and its attributes. This distance decay has been detected in the marginal effect of forested and sports/recreation areas; it is indeed realistic to expect that the maximum marginal value of green is downtown where it is more scarce and—as mentioned in the second section—where it alleviates the negative externalities of the otherwise beneficial centre of urbanization and agglomeration. Formally, this can be expressed as $effect = effect_{\max} - [decay\ rate]*CBD$, with the decay rate varying from year to year. Figure 2b shows the calculated distance decay for the marginal value of forested and sports/recreation areas in Helsinki for each year between 2000 and 2011. The rate of decay varies from year to year, which might be due to the way the broader economic and political forces influence the marginal values, as discussed later on.

FIGURE 2A: PRICE DROP WITH DECREASED PROXIMITY TO THE COASTLINE IN HELSINKI AND ESPOO



Notes:
1. The displayed effect refers to the rapid drop of the expected price per square metre due to moving farther from the Espoo-Helsinki coastline. All other hedonic attributes are assumed constant.
2. Multiple lines refer to multiple years in the 2000-11 period.

FIGURE 2B: DISTANCE DECAY OF THE MARGINAL VALUE OF TWO URBAN GREEN TYPES IN HELSINKI



Notes:
1. The efect of forested areas refers to 100 metres closer.
2. The effect of sports and reretation areas refers to one additional such area per one square kilometre.
3. The figure assumes all other hedonic attributes constant.
4. Multiple lines refer to mulyiple years in the 2000-11 period.

The third theoretical proposition has been that spatially weighted measures of price per unit of housing consumption will illuminate the endogenous component of the residential location model. The measure that has captured this effect is the λ (LAMBDA) coefficient, which is the regression coefficient of a spatially autocorrelated error component. Its use (and thus the use of spatial error models) was supported in the sample by LM tests. This component is not a random residual, but isolates (that is, cleans the dependent variable from; ref. Anselin, 2003) an unobserved neighbourhood effect on the price of a property in the same units as the property value (euro thousand per square metre in the present case). It is usually interpreted as the effect of difficult to operationalize factors, such as the culture or perception of an area, and is thus a potentially good proxy for the modern endogenous amenities that reinforce the high value of a neighbourhood. It is a global spatial externality, which suggests that the unobserved spatial effect concerns all observations but its impact is rather local and decays smoothly in progressively larger rings of neighbours, in the form of $\lambda\mathbf{WX}$, $\lambda^2\mathbf{W}^2\mathbf{X}^2, \ldots, \lambda^n\mathbf{W}^n\mathbf{X}^n$ (Anselin 2003, pp.155-159). Identifying the exact location where this effect is at its strongest needs further analysis and the employment of local (e.g. moving average) models. An alternative measure would have been the ρ (rho) coefficient, which is the regression coefficient of the spatially lagged version of the property value itself. The LM tests have not supported its use (and by extension the use of a spatial lag model) in place of the spatial error component, although exploratory regressions have indicated that the ρ and λ coefficients are numerically similar in the studied sample and both statistically significant.

The abovementioned elements can be interpreted as evidence that the price differentiation mechanism contains a positive feedback element that is akin to what Brueckner et al (1999) imply when describing modern endogenous amenities. Due to the nature of lambda as an unobserved small neighbourhood effect (Ahlgren and Gerkman, 2010; Anselin, 2003; Dubin, 1988; Sedgley et al, 2008; Wilhemsson, 2002), its use as a proxy for modern endogenous amenities makes more sense versus a more narrow interpretation that would see only the price level of a neighbourhood influencing a specific property's price. In other words, a more general endogeneity exists, which most likely does contain the price level of the neighbourhood, but this is intertwined with other difficult-to-grasp factors. The LM tests support this as well, by indicating that while both λ and ρ can be used, it is the former that exhibits the highest significance. A less strict treatment of endogenous amenities is also supported by considering that positive feedback and indeterminacy connected to rather diverse factors are known generators of form, pattern and growth in the city, rather than singular factors such as price; see Batty (2007; 1997) for computational expositions.

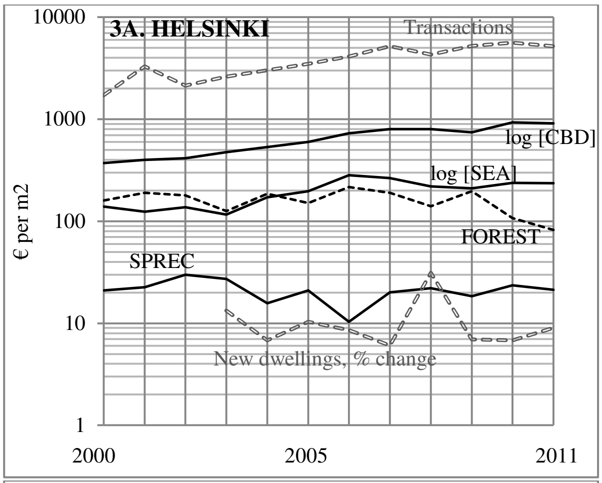
Another interesting element concerns the inter-scale behaviour of λ. Its strong presence across all scales, starting from the 2007-metre hexagons through to the disaggregate level, suggests that the endogenous amenity determinant of value is active both at the citywide and the micro-scale value differentiation mechanism. However, it has a noticeably higher magnitude at the disaggregate level, suggesting that while it participates in the formation of value morphology—or zones—across the city area, it intensifies when further refining values within the already formed zones. Nevertheless, this is potentially misleading as it is known that the value of lambda also depends on model specification (Anselin, 2002; 2003; Gerkman, 2010).

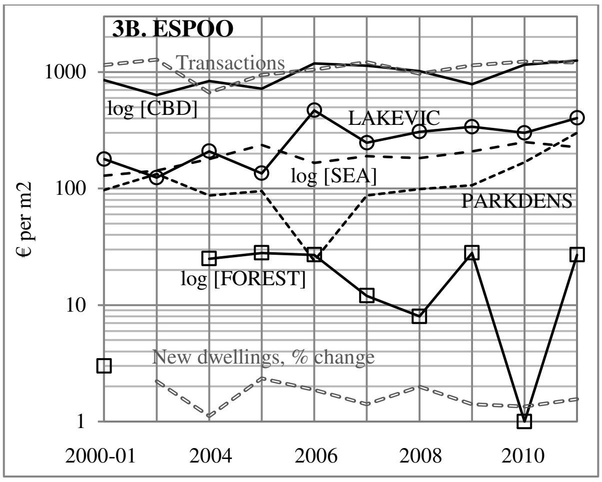
Lastly, a preliminary prompt was conducted into the temporal variation of the estimated marginal effects. While spatial analysis highlights an important dimension of the housing market, it should be kept in mind that price differentiation is naturally not limited to spatial processes like those in the focus of this study. The temporal variation of the discussed marginal effects confirms that the identified spatial dynamics should be placed alongside a broader set of economic and policy factors (Figures 3a, 3b and 3c).

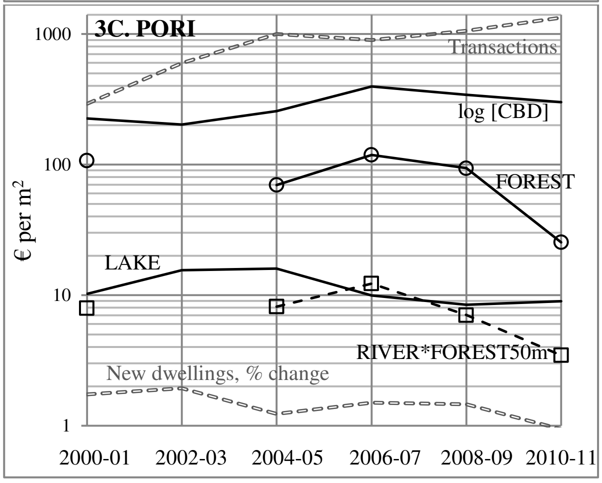
In particular, even after using inflation-adjusted prices, the marginal values exhibit a significant drift from 2000 to 2011, with sharp changes in a few individual years. Generic reasons for this are insufficient residential construction as compared to demand, which is in turn driven by employment and population trends, as well as insufficient rental units. Yet, these generic factors have differentiated effects on the implicit prices of housing attributes, including ecosystems. These differentiated effects—that is, the assumed housing supply and employment trends influence different marginal values in different ways—might be due to variation in the scarcity of these characteristics, possible vintage (drift) effects in the preference scales of home seekers, and interactions between the aforementioned and other effects.

Similarly, further analysis is needed on the sensitivity of the marginal effects of most ecosystems to changes in the volume of real estate transactions, at the same year or with a time lag. Assuming that the volume of transactions is a reliable indicator of the wealth present in the housing market each year, it might be interesting to see whether the amount of money present in the system influences the value of urban ecosystems. However, it should be noted that the transaction volume is partly disturbed by real estate brokers entering or exiting the voluntary data collection scheme. Lastly, an interesting aspect of the temporal variation is that one can discern here, too, the different nature of the CBD and the coastline from the rest of the ecosystem types. A cluster analysis of curves should be able to yield clusters of hedonic attributes in terms of their temporal drift. Similarly, time series analysis should be able to illuminate much of the temporal behaviour in the estimated marginal effects.

FIGURE 3: TEMPORAL VARIATION OF THE ESTIMATED MARGINAL EFFECTS







Notes:
1. Marginal effects in € per m^2.
2. Espoo: The coefficient of FOREST for 2002-03 is statistically insignificant and is omitted.
3. Pori: Estimations for FOREST and RIVER*FOREST50m were not possible for the 2002-03 period.
4. Transactions (amount of) and new dwelling production are used as indicators of broader economic influences.

5 Conclusion: ecosystems in the urban system

The aim of this study has been to highlight the structural role of ecosystems in urban residential property value formation and differentiation, while controlling for other important factors. An amenity-based location model and hedonic function estimations across scales in Helsinki, Espoo and Pori have provided theoretical expectations and empirical support concerning the details of the studied structure. The majority of the estimations exhibit high statistical significance, model stability across samples of different years, and a satisfactory grasp of the total price variation. Even so, in a system as complex as the urban, the focus cannot be at the face value of the marginal effects. Variation in estimated hedonic coefficients is a reported source of uncertainty, largely stemming from the choice of empirical model and its parameters (Beron et al, 2010; Gerkman, 2012). This reinforces the necessity to emphasize structure rather than singular marginal values.

On one hand, the estimations show that ecosystems influence price across spatial scales. This behaviour is consistent with findings in urban complexity research on the fractal nature of several urban phenomena (Batty 2007). It is suggested to identify the marginal effects of the coarser scales with the exogenous environmental amenity effect outlined in Brueckner et al (1999), responsible for the formation of a city-wide morphology of property value. The exogenous effect diversifies with more kinds of ecosystems when moving towards the micro-scale, and is much more specific to the property or its immediate neighbourhood. It is suggested to view this as a separate mechanism that refines and fragments the value zones established by the general spatial equilibrium. Thus, it can be said that the city-wide mechanism and the few ecological factors that participate in it form value in an equilibrium fashion, whereas the micro-scale mechanism and its numerous factors differentiate value in a dynamic fashion. Furthermore, the same ecosystem can participate in both mechanisms. For instance, the presence of the sea as a large, ever-present geographical feature forms two general value zones (expected and observed high values nearby and lower values farther away), but inside the high value zone that has been formed in its general vicinity the sea further increases price for those few properties immediately next to it, along with plenty of other micro-factors. The above further strengthens the fractal behaviour assumption. Understanding price formation in this way is consistent with the characteristically noisy spatial morphology of value that is observed in the real world.

On the other hand, a number of details are visible. The diversity of marginal effects indicates that the housing market is sensitive to the specific kind of service that is received by the ecosystem, especially concerning urban green, as well as that it is often a combination of ecosystem services that influence value. Distance decay in the marginal values of the ecosystem is also evident. This suggests on one hand that the marginal effects can be quite local, and on the other that they are spatially variable. However, as previously noted, the concept of “local” must be understood properly since the models employed are global and most of the effects are smoothing out rather than disappearing. The endogenous amenity component suggested by Brueckner et al (1999) is present through the spatial error term of the estimated hedonic functions. The commonality between the two is thus far focused on the interpretation of both as a neighbourhood premium connected to culture, perception or similar spatial unobservable features; more statistical analysis is needed to verify the endogeneity character.

The indication that the urban ecosystem is active as a price determinant across spatial scales and highly contextual in its marginal effects brings forth three important implications for adaptation and sustainability in cities. Firstly, local agent action and citywide mechanisms have to be understood as one system, which replaces monolithic and top-down planning programs with a more pragmatic and sensitive to local conditions approach, as Batty (2007) has showcased. Secondly, as Brooks (2011) has discussed, either poles in the efficiency–equity continuum are unrealistic because they are both too general to grasp urban economic dynamics. In particular, it is erroneous to think of ecosystems either as something to be placed everywhere (equity) or something readily substituted (efficiency); ecosystems are structural elements of the urban economy and their true effects are much more complex than the equity–efficiency dipole is configured to grasp. Thirdly, the spatial and temporal particularities of the effects of the urban ecosystem and its services on urban economic behaviour have to become apparent, and here processes other than the spatial ones discussed in this text have to be taken into account; economic cycles, housing policy and housing supply deficiencies with respect to the demand placed by population and employment dynamics seem to influence also the value of ecosystems. All those elements are necessary whether the focus is on change of current, or adaptation to new ecological conditions, as the ecosystem is a major link between biophysical and socioeconomic phenomena in the city.

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Appendix: regression results at the disaggregate level

TABLE 3A: HEDONIC ESTIMATIONS AT THE DISAGGREGATE LEVEL, HELSINKI APARTMENTS, YEARS 2000–2011

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Intercept	7.156***	6.888***	7.575***	8.233***	9.26***	10.033***	12.189***	12.749***	12.294***	11.827***	14.034***	13.804***
DEBT	–.051	.568***	–.575***	–.583***	–.524***	–.734***	–.313***	–.509***	–.518***	–.66***	–.534***	–.616***
MAINT	–.039***	–.035***	.007	–.02**	–.04***	–.032***	– .054***	–.017	–.01	–.011	–.009	–.017·
ROOMS	–.067***	–.052***	–.129***	–.124***	–.1***	–.11***	–.119***	–.152***	–.142***	–.192***	–.254	–.236***
AGE	–.012***	–.01***	–.015***	–.018***	–.017***	–.017***	–.02***	–.021***	–.026***	–.023***	–.024***	–.021***
$[AGE]^2$	9.979e-5***	1.058e-4***	1.409e-4***	1.467e-4***	1.426e-4***	1.552e-4***	1.856e-4***	1.774e-4***	2.035e-4***	2.132e-4***	1.966e-4***	1.812e-4***
ONSALE	–.001***	–.001***	–.000	–.001***	–.000***	–.001***	–.002***	–.001***	–.001***	–.001***	–.000***	–.000*
FLOOR	.039***	.043***	.03***	.037***	.032***	.056***	.051***	.065***	.064***	.065***	.062***	.067***
BADCOND	–.269***	–.097***	–.332***	–.407***	–.392***	–.442***	–.453***	–.512***	–.601***	–.598***	– .543***	–.464***
AVGCOND	–.213***	–.11***	–.12***	–.181***	–.23***	–.28***	–.296***	–.259***	–.279***	–.237***	– .226	–.281***
OWNPLOT	.142***	.149***	.055·	.149***	.214***	.192***	.194***	.162***	.256***	.259***	.281	.304***
log [CBD]	–.372***	–.399***	–.416***	–.477***	–.535***	–.602***	–.73***	–.798***	–.803***	–.746***	– .932***	–.911***
log [SEA]	–.139***	–.124***	–.137***	–.117***	–.172***	–.197***	–.283***	–.266***	–.22***	–.209***	– .238***	–.236***
FOREST	–.002	–.002***	–.002***	–.001***	–.002***	–.002***	–.002***	–.002***	–.001**	–.002***	– .001***	–.001**
CBD*FOREST	1.391e-4	2.99e-7***	2.564e-7**	1.578e-7*	2.112e-7**	2.541e-7***	3.225e-7***	1.905e-7***	2.899e-7***	2.929e-7***	2.607e-7***	1.868e-7***
SPRECDENS	.021***	.023***	.03***	.027***	.016***	.021***	.01·	.02***	.022***	.018***	.024***	.021***
CBD*SPRECDENS	–3.298e-6***	–3.779e-6***	–4.545e-6***	–4.314e-6***	–2.853e-6***	–3.072e-6***	–1.969e-6*	–2.952e-6***	2.718e-6***	–2.473e-6***	–2.816e-6***	–2.19e-6***
LAMBDA (λ)	.625***	.578***	.446***	.598***	.704***	.728***	.793***	.64***	.655***	.559***	.597***	.608***
Negelkerke R^2	.67	.66	.65	.76	.79	.79	.84	.79	.76	.76	.79	.81
N (of properties)	1717	3296	2138	2617	3030	3483	4129	5201	4301	5231	5640	5200

Notes:
1. Significance levels: (***) 0.000; (**) 0.001; (*) 0.01; (·) 0.05.
2. Lambda is the spatially autocorrelated error component, interpreted as an unobserved neighbourhood effect on value.
3. The reported coefficients are interpreted as marginal effects and correspond to € thousand per m^2.
4. Log refers to the natural logarithm.

TABLE 3B: HEDONIC ESTIMATIONS AT THE DISAGGREGATE LEVEL, ESPOO APARTMENTS, YEARS 2000–2011

	2000-01	2002-03	2004	2005	2006	2007	2008	2009	2010	2011
Intercept	11.742***	10.005***	12.946***	12.625***	16.359***	16.148***	15.017***	13.576***	17.515***	18.109***
DEBT	–.51***	–.683***	–.807***	–.864***	–.963***	–.741***	–.575***	–.987***	–.846***	–.77***
FLOORSP	–.008***	–.009***	–.007***	–.009***	–.008***	–.009***	–.01***	–.012***	–.013***	–.01***
FLOOR	.022***	.018***	.028***	.006	.031***	.025***	.018·	.002	.031***	.038***
BADCND	–.121***	–.305***	–.217	–.213*	–.314***	–.47***	–.441***	–.398***	–.333***	–.252*
AVGCOND	–.118***	–.117***	–.171***	–.22***	–.233***	–.164***	–.181***	–.173***	–.173***	–.215***
AGE	–.012***	–.023***	–.059***	–.056***	–.047***	–.036***	–.039***	–.06***	–.06***	–.05***
$[AGE]^2$		1.774e-4·	7.027e-4***	5.992e-4***	4.647e-4***	2.016e-4·	2.752e-4*	6.3e-4***	5.404e-4***	3.164e-4**
log [CBD]	–.854***	–.635***	–.837***	–.721***	–1.185***	–1.134***	–1.02***	–.787***	–1.158***	–1.255***
log [SEA]	–.129***	–.143***	–.179***	–.236***	–.166***	–.19***	–.183***	–.209***	–.25***	–.227***
PARKDENS	.097**	.133***	.087·	.095·	.024	.087*	.099*	.107*	.168***	.3***
log [FORES]	–.003***	.002	–.025·	–.028**	–.027*	–.012	–.008	–.028**	–.001*	–.027
LAKEVIC	.179***	.124·	.209·	.135*	.469***	.247*	.307*	.338·	.3	.403**
ONSALE				–.000·	.000	–.001**	–.001***			
YEAR	–.094***	.129***								
LAMBDA (λ)	.667***	.672***	.686***	.837***	.786***	.578***	.466***	.588***	.554***	.667***
Negelkerke R^2	.71	.74	.74	.86	.87	.75	.67	.76	.76	.79
N (of properties)	1145	1274	667	941	1048	1214	968	1143	1227	1209

Notes:
1. Significance levels: (***) 0.000; (**) 0.001; (*) 0.01; (·) 0.05.
2. Lambda is the spatially autocorrelated error component, interpreted as an unobserved neighbourhood effect on value.
3. The reported coefficients are interpreted as marginal effects and correspond to € thousand per m^2.
4. Log refers to the natural logarithm.

TABLE 3C: HEDONIC ESTIMATIONS AT THE DISAGGREGATE LEVEL, PORI APARTMENTS, TWO-YEAR PERIODS DURING 2000–2011

	2000-01	2002-03	2004-05	2006-07	2008-09	2010-11
Intercept	3.395***	3.41***	4.332***	5.251***	5.06***	4.826***
DEBT	–.685***	–.951***	–.927***	–1.01***	–.812***	–.763***
FLOORSP	–.000**	–.003***	–.004***	–.004***	–.005***	–.004***
FLOOR	.018*	.008·	.015***	.016***	.01*	–.025***
AGE	–.017***	–.013***	–.023***	–.017***	–.028***	–.031***
$[AGE]^2$	1.109e-4***	6.277e-5***	1.448e-4***	8.845e-5***	2.055e-4***	2.113e-4***
BADCND		–.216**		–.372***	–.367***	–.359***
AVGCOND		–.151***	–.075***	–.133***	–.158***	–.154***
log [CBD]	–.225***	–.203***	–.257***	–.395***	–.342***	–.299***
LAKE	–.000**	–.000***	–.000***	–.000***	–.000***	–.000***
FOREST	–.001**		–.001***	–.001***	–.001***	
FORES50*RIVER	–.001·		–.000***	–.000***	–.000*	
ONSALE					–.000**	–.000***
NORTH		–.276***	–.392***	–.349***	–.321***	–.241***
YEAR	–.064.	.068***				.082***
LAMBDA (λ)	.329***	.636***	.73***	.647***	.663***	.474***
Negelkerke R^2	.59	.79	.88	.84	.81	.78
N (of properties)	292	599	1002	900	1059	1331

Notes:
1. Significance levels: (***) 0.000; (**) 0.001; (*) 0.01; (·) 0.05.
2. Lambda is the spatially autocorrelated error component, interpreted as an unobserved neighbourhood effect on value.
3. The reported coefficients are interpreted as marginal effects and correspond to € thousand per m^2.
4. Log refers to the natural logarithm.