Multidimensional Spatial Heterogeneity in Ecosystem Service Values: Advancing the Frontier

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Spatial Heterogeneity in Values

- Spatial heterogeneity in ecosystem service value occurs because of relationships between spatial variations in ecosystem service demand and supply.
- Failure to recognize this heterogeneity can lead to large errors when calculating per household or aggregate value (typically willingness to pay, or WTP).
- Within stated preference analysis (survey-based valuation), spatial value heterogeneity is generally modeled as a function of distance between households and resources.
    - May be discrete or continuous.
    - Sometimes addresses directionality and substitutes.

Distance Decay in Ecosystem Service Values

- For many ecosystem services, the value of the service declines as a person moves farther away—this is called distance decay.

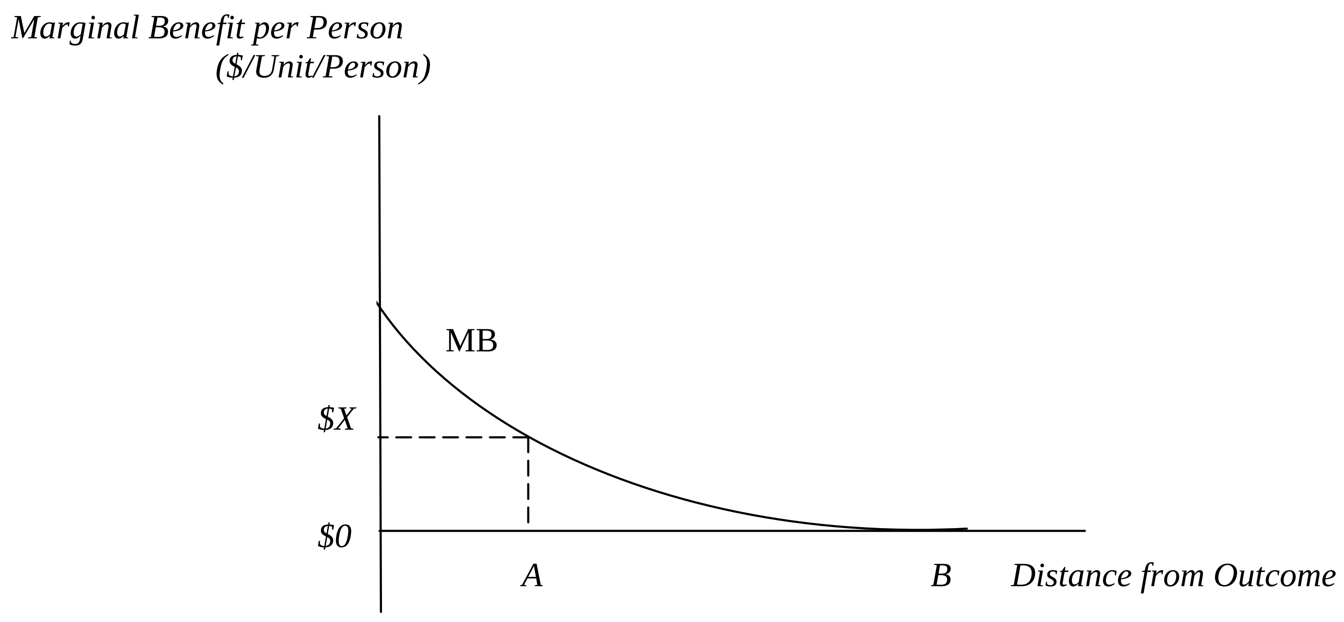
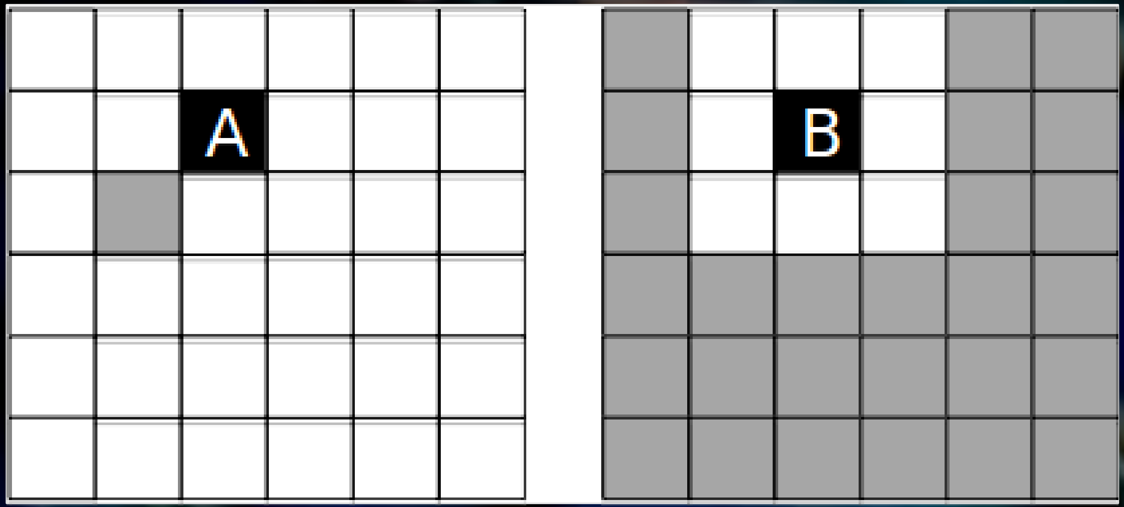


Figure 2.2 Marginal Benefits and Scale over Distance (or Populations Over Greater Areas)

Spatial Welfare Heterogeneity

- Other approaches to spatial heterogeneity include spatial threshold (or border) analyses.
- Less common approaches include kriging, spatial autocorrelation (Campbell et al. 2008, 2009) and hot spots (Johnston and Ramachandran 2014, Meyerhoff 2013).
- These and related approaches are all based on distance as the fundamental spatial unit (a one-dimensional measure).
- Commonly measured as the "distance to nearest point" between each household and an affected resource, either using geodesic or travel distance.
- But what about areas (two-dimensional measures)?

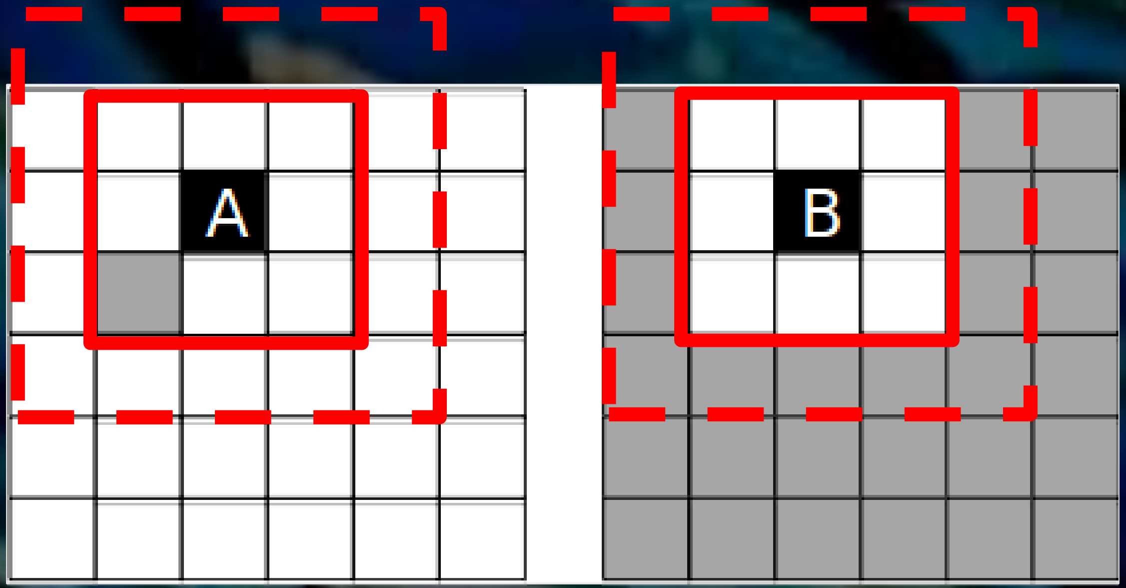
A Simple Illustration



- Household A is at distance zero from closest affected resource providing a service (e.g., restored riparian land).
- Household B is at distance one from the closest resource, but has a larger quantity in close proximity.
- Which household is "closer"?
- Which will have a higher value for improvements?

Questioning the Distance-Only Paradigm

- This paper develops an approach to model heterogeneity in stated preference WTP linked to two-dimensional measures.
  - Models heterogeneity linked to the *quantity* of an resource surrounding each beneficiary (i.e., quantity-at-distance-*x*).
  - The distance radius for quantity measurements is optimized using model fit.



Relationship to Prior Work

- The use of areas-within-distances is common in some types of revealed preference analysis (e.g., hedonics).
- Similar approaches are rare as a means to characterize value heterogeneity within stated preference models.
- The few existing stated preference analyses that use quantity-within-distance measures do so using ad hoc distances (e.g., Yao et al. 2014; Czajkowski et al. 2016).
- An infinite number of possible distance bands (and hence areas) exist around each beneficiary's home, and selecting the "best" distance *x* is not trivial.
- This analysis chooses the optimal distance band (radius) using an iterative grid search over model log-likelihoods.

The Model

- Model contrasts distance-to-nearest-point (distance decay) and quantity-within-distance-*x* analysis, for policies affecting riparian land.
- Approaches illustrated using a random utility framework for household *h* and policy scenario *p*.
- $U_{ph} = \boldsymbol{\gamma_h}'\mathbf{X_{ph}} - \lambda_h C_{ph} + \boldsymbol{\psi_h}'(s_{phg}\mathbf{X_{ph}}) - \phi_h(s_{phg}C_{ph}) + \varepsilon_{ph}$
- $\mathbf{X_{ph}}$ are policy outcomes; C_{ph} is household cost.
- s_{phg} is distance-to-nearest-point or quantity-within-distance-*x*, with $g=\{1,2\}$ identifying the spatial measure.
- $\boldsymbol{\gamma_h}$, λ_h, $\boldsymbol{\psi_h}$, ϕ_h and are conforming parameter vectors or scalars to be estimated.

Stated Preference Choice Experiments

- Methods and results are illustrated using stated preference discrete choice experiments.
  - Survey-based methods that estimate values from respondents' votes over different policy options.
- Respondents choose among policies with different effects (e.g., on ecosystem services) and costs.
- By evaluating votes over many alternatives, we calculate tradeoffs that reveal values (willingness to pay, or WTP).
- Results are illustrated using a choice experiment on riparian land restoration in the Merriland, Branch Brook, and Little River (MBLR)Watershed in Maine, USA.

The Choice Experiment—Technical Details

- Choice experiment was developed over 3 years in coordination with the Wells National Estuarine Research Reserve.
- Testing and revision including 9 focus groups plus cognitive interviews, verbal protocols and expert review.
- Surveys implemented December 2013 – January 2014, with multiple wave mailings to maximize response.
- Mailed to 2,544 random households in the three towns.
- Of deliverable surveys, 734 were returned, for a response rate of 34% (of deliverable surveys).

Example Choice Question

COMPARING PROTECTION OPTIONS

The upcoming questions will ask you to compare different ways of protecting riparian land in Kennebunk, Sanford and Wells, and vote for the ones you prefer. You may also vote to reject the proposed programs and retain the status quo. **Effects of each option will be described by the following effects, as estimated by scientists:**

Effect	What it Means
Natural Riparian Land	The amount of riparian land covered by natural vegetation. Currently about 91% of the land is in natural condition. With no action **85%** of riparian land in the area (4000 acres) will remain in natural condition in 5-10 years.
River Ecology	Average ecological condition of area rivers, measured by the diversity of small organisms (dragonflies, mayflies, etc.) that live there. A score of 100% is the best possible condition in the area. A score of 0% means nothing lives in the water. With no action, the ecological condition in area rivers will be **55%** in 5-10 years. The score today is about 60%.
Recreational Fish	The number of recreational fish in area rivers, measured by scientific sampling of brook trout. A score of 100% would mean that area rivers contain the maximum number of trout possible (30 trout per 1000 sq. feet). Today there are about 19 trout per 1000 sq. feet. With no action, scientists predict there will be an average of 17 trout per 1000 sq. feet (**55%** of the most possible) in 5-10 years.
Safe Swimming	The percentage of days in which government tests show that area beaches (Laudholm, Drakes Island, Crescent Surf, and Parson) are safe for swimming. 100% means that all tests show water safe for swimming. With no action, scientists predict **85%** of tests will show water safe for swimming in 5-10 years.
Development Setback	The minimum width of the riparian area where development is restricted. Currently development and clearing is restricted within a minimum distance of **100 feet from rivers** and **25 feet from streams**. This distance is larger in some areas and for some types of development. Existing (legal) development would be grandfathered if setbacks change.
Enforcement	Whether enforcement is increased to prevent illegal development or clearing on riparian land. This could include inspections on private land if violations are suspected. Currently, inspections can only occur when a violation has been reported or as part of permitting.
$ Cost to your Household per Year	How much the policy will cost your household in unavoidable annual taxes and fees. These are guaranteed to only be spent on the protection option that is indicated.

YOU WILL BE ASKED TO VOTE

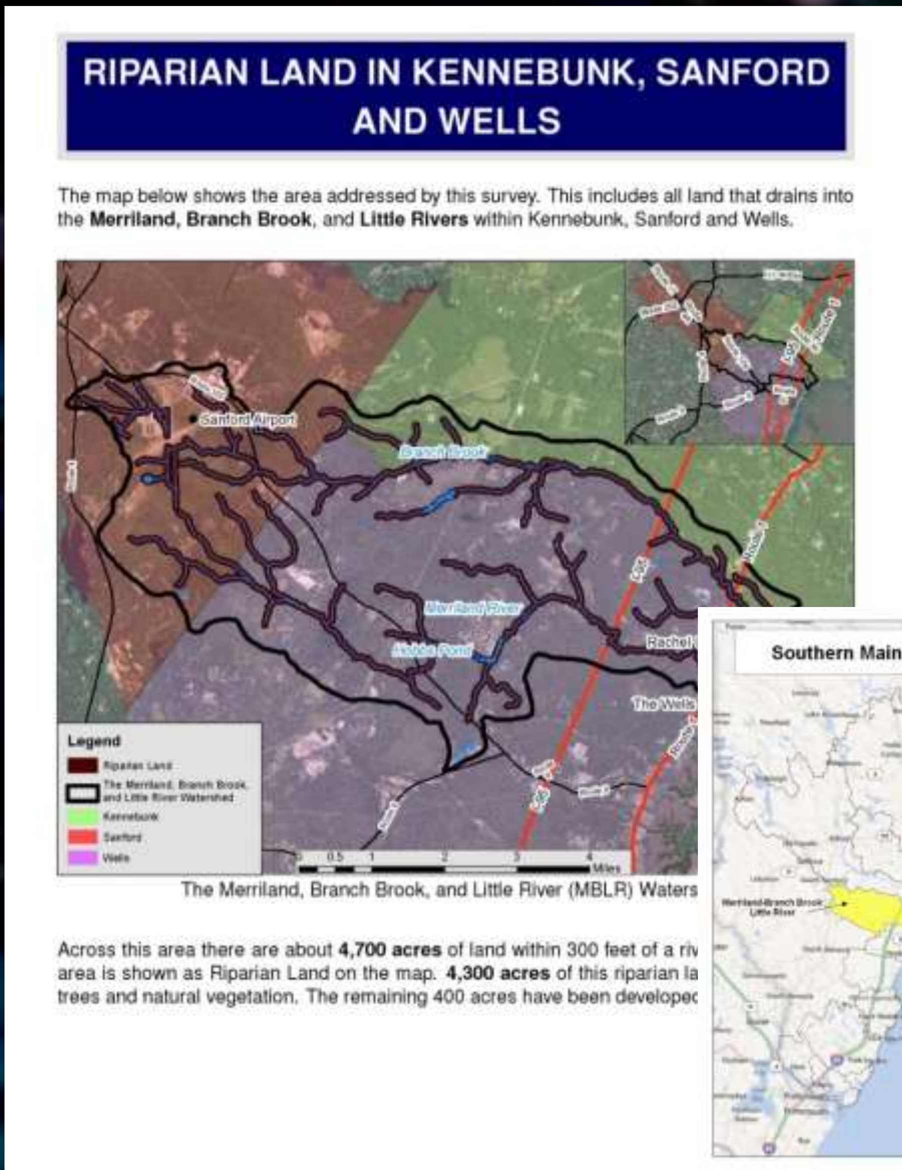
After considering the current situation and possible protection effects and methods, which do you prefer? You will be given choices and asked to vote for the option you prefer by checking the appropriate box. **Questions will look similar to the sample below.**

SAMPLE QUESTION:

Method or Effect of Protection	In 5-10 years under the Current Situation	In 5-10 years under Option A	In 5-10 years under Option B
Riparian Land Condition	**85%** 4000 out of 4700 riparian acres covered by natural vegetation	**87%** 4100 out of 4700 riparian acres covered by natural vegetation	**95%** 4500 out of 4700 riparian acres covered by natural vegetation
River Ecology	**55%** of best possible (100%) ecological condition	**85%** of best possible (100%) ecological condition	**85%** of best possible (100%) ecological condition
Recreational Fish	**55%** 17 out of 30 possible fish per 1000 sq. feet	**75%** 23 out of 30 possible fish per 1000 sq. feet	**55%** 17 out of 30 possible fish per 1000 sq. feet
Safe Swimming	**85%** of beach tests meet safe swimming guidelines	**95%** of beach tests meet safe swimming guidelines	**85%** of beach tests meet safe swimming guidelines
Development Setback	**100 feet** required between development and rivers; 25 feet for streams	**150 feet** required between development and rivers; 75 feet for streams	**100 feet** required between development and rivers; 25 feet for streams
Enforcement	**No Change** in enforcement and inspections	**No Change** in enforcement and inspections	**Increased** enforcement and inspections
$ Cost to your Household per Year	**$0** Increase in Annual Taxes or Fees	**$45** Increase in Annual Taxes or Fees	**$5** Increase in Annual Taxes or Fees
HOW WOULD YOU VOTE? (CHOOSE ONLY ONE) I vote for	X NO NEW PROTECTION	X I vote for OPTION A	X I vote for OPTION B

	If you prefer **No New Action** Check Here	If you prefer **Option A** Check Here	If you prefer **Option B** Check Here

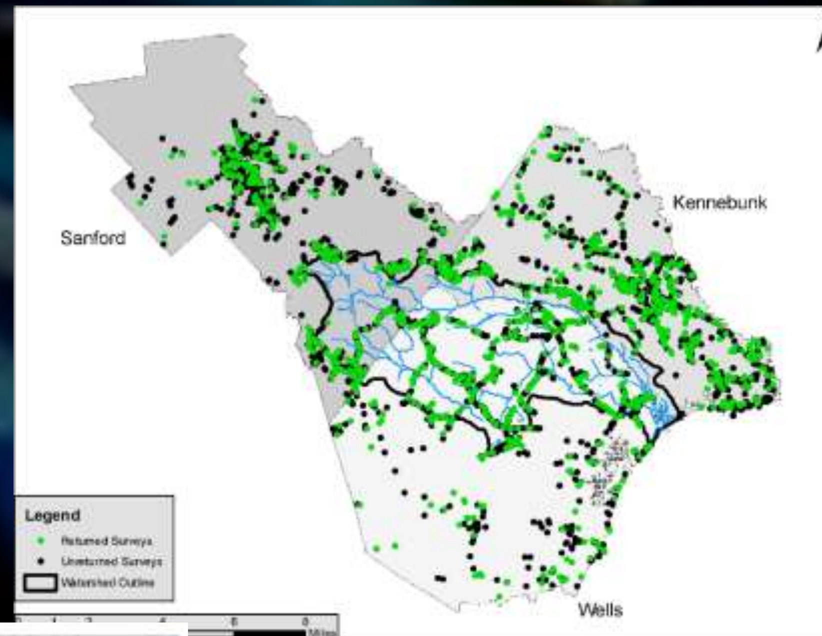
Scenarios and Responses in Space

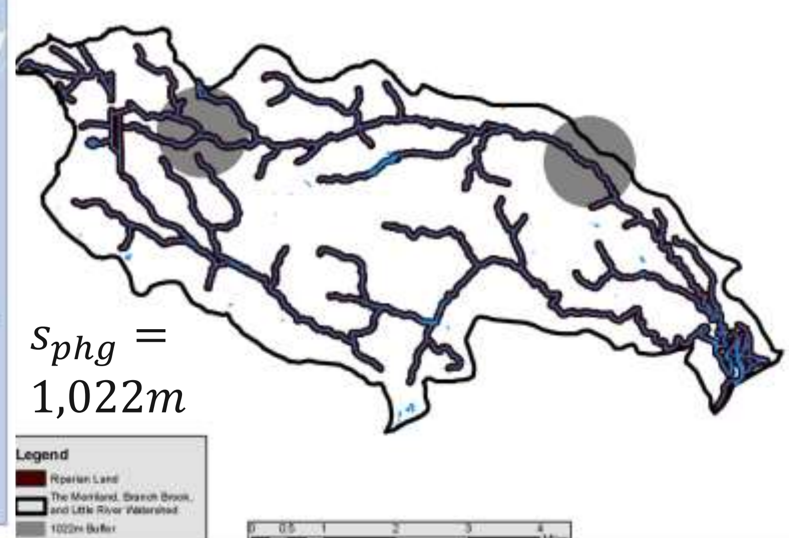

RIPARIAN LAND IN KENNEBUNK, SANFORD AND WELLS

The map below shows the area addressed by this survey. This includes all land that drains into the **Merriland, Branch Brook**, and **Little Rivers** within Kennebunk, Sanford and Wells.

The Merriland, Branch Brook, and Little River (MBLR) Waters

Across this area there are about **4,700 acres** of land within 300 feet of a riv
area is shown as Riparian Land on the map. **4,300 acres** of this riparian la
trees and natural vegetation. The remaining 400 acres have been developec





$s_{phg} =$
$1{,}022m$

Implementation and Modeling

- Two-step estimation of the quantity-within-distance model.
- First stage determines the optimal distance band using an iterative grid search algorithm over preference-space mixed logit log-likelihoods.
  - Identifies optimal distance band of $s_{phg} = 1{,}022m$.
- The second stage uses this optimal distance band to estimate the final discrete choice model in WTP-space (Scarpa et al. 2008; Train and Weeks 2005).
- Distance to nearest riparian land is used for parallel distance decay model.
- All ecological attributes included in percentage form, relative to the ecological reference condition.

WTP-Space Results: Distance Decay

Attribute	Main Effect Coefficients $[\hat{\omega}_h, \hat{\lambda}_h]$ (Std. Error)	Standard Deviations of $\hat{\omega}_h$ and $\hat{\lambda}_h$ (Std. Error)	Area interactions $[\hat{\eta}_h, \hat{\theta}_h]$ (Std. Error)
ASC (status quo)	-65.612*** (12.199)	133.890*** (14.283)	-0.822 (3.151)
Riparian Land Condition	0.283 (0.546)	1.405 (0.869)	0.157 (0.197)
River Condition	0.908*** (0.183)	1.194*** (0.327)	-0.037 (0.068)
Recreational Fishing	0.986*** (0.185)	1.316*** (0.342)	**-0.167*** (0.067)**
Safe Swimming	1.401*** (0.566)	0.360 (1.259)	0.248 (0.212)
Development Setbacks	0.152** (0.059)	0.522*** (0.069)	-0.009 (0.022)
Enforcement	15.560*** (3.467)	7.728 (7.437)	0.791 (1.257)
ln(λ_h)	-3.072*** (0.196)	0.660*** (0.306)	0.073 (0.080)
Observations (N)	2136	Log-Likelihood	-1809.31
Pseudo R^2	0.22	Prob. > χ^2	0.0001

WTP-Space Results: Area-within-Distance (1,200m)

Attribute	Main Effect Coefficients $[\hat{\omega}_h, \hat{\lambda}_h]$ (Std. Error)	Standard Deviations of $\hat{\omega}_h$ and $\hat{\lambda}_h$ (Std. Error)	Area interactions $[\hat{\eta}_h, \hat{\theta}_h]$ (Std. Error)
ASC (status quo)	-63.476*** (11.498)	131.977*** (15.442)	1.397 (24.730)
Riparian Land Condition	0.482 (0.457)	2.143*** (0.947)	0.402 (1.371)
River Condition	0.713*** (0.170)	1.462*** (0.272)	0.620 (0.496)
Recreational Fishing	0.439*** (0.154)	1.342*** (0.306)	**1.346*** (0.491)**
Safe Swimming	1.938*** (0.504)	0.483 (0.904)	-0.684 (1.527)
Development Setbacks	0.045 (0.050)	0.474*** (0.068)	**0.413** (0.179)**
Enforcement	16.635*** (2.924)	7.715 (6.958)	6.088 (8.777)
ln(λ_h)	-2.836*** (0.234)	0.834*** (0.321)	0.096 (0.416)
Observations (N)	2136	Log-Likelihood	-1800.82
Pseudo R^2	0.22	Prob. > χ^2	0.0001

Illustration: WTP for a 100 ft. Increase in *Development Setbacks* Across Three Towns

Town	Mean WTP: Quantity-within-Distance Model (Std. Dev.)	Mean WTP: Distance Decay Model (Std. Dev.)	WTP Difference: Quantity-within-Distance versus Distance Decay (Std. Dev.)	Prob: [H_0: WTP Difference = 0][a]
Kennebunk, Maine (N=266)	6.56 (0.29)	12.96 (0.08)	-6.40 (0.25)	0.0001
Sanford, Maine (N=192)	11.65 (0.71)	13.16 (0.15)	-1.51 (0.63)	0.0175
Wells, Maine (N=276)	21.57 (0.80)	14.24 (0.96)	7.33 (0.74)	0.0001

WTP calculated using distance and area data for each observation in the sample. Reported estimates reflect means and standard deviations for households in each sampled town.

- Required development setbacks are determined at the town level in the US, so town-level WTP is most relevant.

Conclusions

- Results of the analysis demonstrate the insight available through two-dimensional models of spatial heterogeneity.
- Compared to a distance-to-nearest-point model, the quantity-within-distance model appears to better capture spatial WTP variation across our case study area.
- Although models such as those proposed here are more computationally intensive, they can identify patterns invisible to other approaches.
- A lack of WTP variation associated with one-dimensional distance measures should not be interpreted as a sign of homogeneity in ecosystem service values.
- Other types of spatial heterogeneity may be equally if not more relevant for modeling and policy analysis.

Questions?

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