Automating & Capturing Amenity-Value using the Conservation Easement Visibility Index in ArcGIS

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Abstract:

This paper is from the methodological section of my recently completed dissertation[1] and covers at least three topics for the GIS users: urban and regional planning, use of 3D GIS and use as a measurement to see the impacts of land conservation on property markets. Using spatial analyst and 3d extensions in ArcGIS, I developed Conservation Easement Visibility Index (CEVI), a joint measure of distance-decay and viewshed function. ArcGIS was used in developing input variables for modeling purpose. Using hedonic modeling framework, I captured the amenity-values generated by the Conservation Easement (CE) protected land parcels on surrounding homes. The findings were very interesting: statistically, distance and view both were found insignificant; however, their joint effect captured via the CEVI was significant. The paper makes a methodological contribution and informs land conservation agencies in prioritizing worthy lands for conservation purposes,[2] also helps real estate developers in spatially targeting developments that could internalize greater externalities, and lastly to local authorities in forming sound land use policies to promote conservation. This paper lays greater emphasis on development of variable and then concludes how those variables could be used in modeling.

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[1] Mittal, Jay. 2011. Measuring Externality Effect of Voluntarily Protected Undeveloped Properties on Surrounding Home Values: Evidence from Worcester, Massachusetts. PhD dissertation, University of Cincinnati, Ann Arbor: ProQuest/UMI, date. (Publication No. 3481322.)

[2] that externalize the highest economic benefits to its surrounding

Research Background

In my dissertation research[3] I was interested in measuring the effect on home values, measured by proximity and view of amenity generating privately protected land parcels (such privately help and publicly protected land parcels are also known as conservation easements). More specifically in my research, I was interested in the relationship between conservation-easement parcels and the values of surrounding homes using two amenity value capturing variables – proximity and viewability using hedonic price modeling framework.

Using the 3-D GIS, the externality-capturing explanatory variables as above were developed. Those include varaibles such as distance or proximity from homes to the CE parcels, and viewable areas of CE parcels from homes, and additionally, I used Conservation Easement Visibility Index (CEVI), which is a relative index that measures both the visibility and proximity together through a single variable for home samples.

Focus of the Paper

In this paper, I first explained the amenity capturing variables and how some of these processes be automated and then later, I present a detailed multi-step process of developing one of the most important variables, which my co-author Lin Liu and I call "Conservation Easement Visibility Index" (CEVI). As mentioned earlier, this variable captures both, the view, and the distance effect in a single measurement that captures the combined effect of ability to view and being closer to the amenity.

The Five Amenity Capturing Explanatory Variables

There were five externality capturing variables that were developed for this paper. Two of these are the *proximity measures*, and two are the *viewable-area measures*. These proximity variables are DistCESq, the square of Euclidean distance, which is a straight line distance from each home sample to the nearest CE parcels, and the similarly squared distance from the nearest visible CE parcel. The second set of variables is about viewable area, and these compute the viewable area of CE parcels from each home and are expressed in two ways. First is the Tot_ViewAr, which is

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[3] Mittal, Jay. 2011. Measuring Externality Effect of Voluntarily Protected Undeveloped Properties on Surrounding Home Values: Evidence from Worcester, Massachusetts. PhD dissertation, University of Cincinnati, Ann Arbor: ProQuest/UMI, date. (Publication No. 3481322.)

a sum of all the viewable areas of CE parcels from each sample home, and the second is Nr_ViewAr, the viewable areas of the nearest CE parcel. These view variables were developed using digital elevation model (DEM) and the viewshed analysis.[4]

The fifth and the last one the most important and is an interaction variable that uses both the viewability and the proximity variables in a single variable and is expressed in an index form and is been titled as CEVI Index in this paper. It is a weighted sum of inverse distance, a variable similar to the accessibility measure, and it evaluates the interaction effect of both the viewability and the squared Euclidean distance. What these five variables really mean in a geographical sense is shown in figures 1 and 2.

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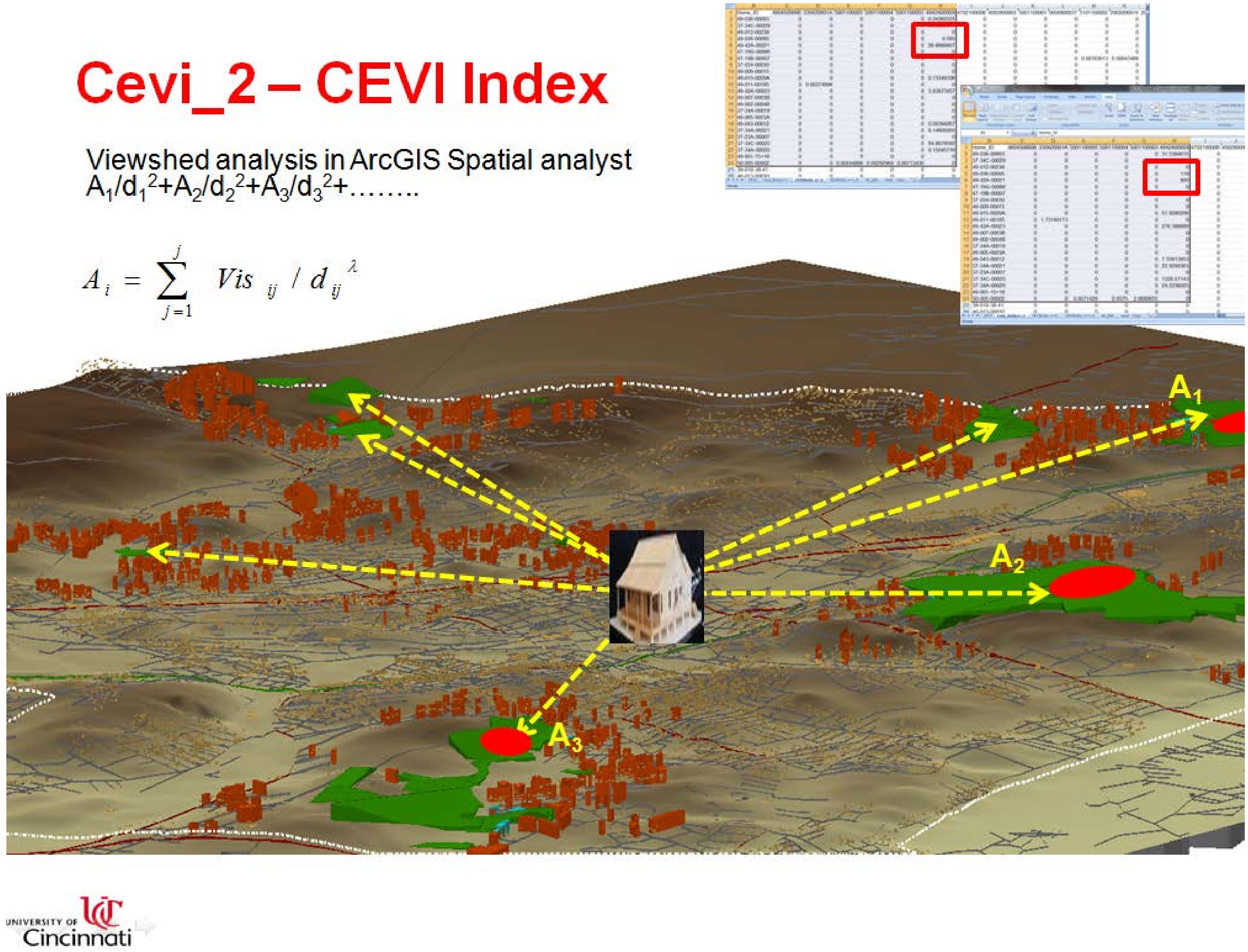
[4] Shultz and Schmitz, "Viewshed Analyses," (2008): 224-232.;
Lake et al., "Using GIS," (2000): 521-541.;
Lake et al., "Modeling Environmental Influences," (1998): 121-136.;
Wolverton, "Empirical Study," 1 (1997): 48-57.;
Sander and Manson, "Heights and Locations," (2007): 257–270.;
Sander and Polasky, "Value of Views," (2009): 837–845.

Figure1. Conservation Easement Visibility Index (CEVI)



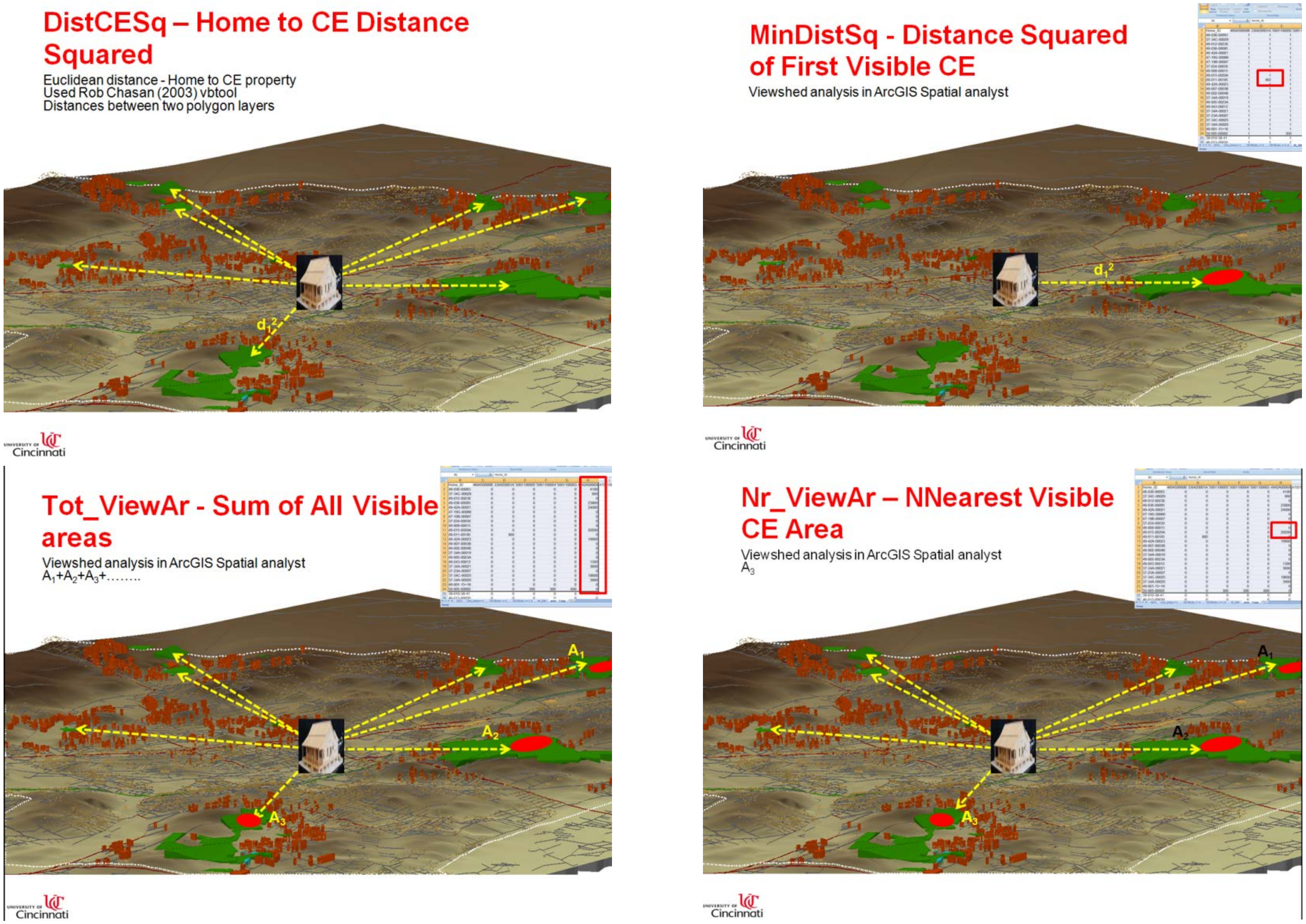
Cevi_2 – CEVI Index

Viewshed analysis in ArcGIS Spatial analyst

$A_1/d_1^2+A_2/d_2^2+A_3/d_3^2+\dots\dots$

$$A_i = \sum_{j=1}^{j} Vis_{ij} / d_{ij}^{\lambda}$$

Figure 2 *Proximity* and *View* Variables



DistCESq – Home to CE Distance Squared

Euclidean distance - Home to CE property
Used Rob Chasan (2003) vbtool
Distances between two polygon layers

MinDistSq - Distance Squared of First Visible CE

Viewshed analysis in ArcGIS Spatial analyst

Tot_ViewAr - Sum of All Visible areas

Viewshed analysis in ArcGIS Spatial analyst
$A_1+A_2+A_3+$…….

Nr_ViewAr – NNearest Visible CE Area

Viewshed analysis in ArcGIS Spatial analyst
A_3

Section 1: Measuring View

View has been defined in many ways in the past studies. The most common way view has been used is in its qualitative terms, for example, view has been used as binary variable such as visibility (yes/ No) or, view as quality variables such as good, better, or best view. View is also used as a near view or a distant view. Surrounding land uses have also been used as a proxy for View. Similarly, various measures such as diversity of land use, percentage of open space are used to define view to an environmental externality generator. The other studies present more traditional qualitative view-capturing process such as using physical verifications and site surveys, which could be prohibitively time consuming, depending on the number of properties considered and how views have been qualitatively assessed. Literature also explains other ways in which view variable is used is as a dummy variable showing if a view is available or not, or view as a qualitative variable on a scale of 1 to 5, views as abutting property, and a view proxy using land use diversity as a primary variable for a 400-foot radius from each home sample. A very few studies have used 3-D GIS and DEM to automate the view variable. In this paper, 3-D GIS technology was used and was found very useful in automating and quantifying views. The advantages are several: views can be measured objectively, automatically, without physically visiting the home sites. The table below presents key papers that have been used in automation of view using GIS and Viewshed.

Table 1 View Automation method using GIS and Viewshed

Authors (Year)	Methodological Contributions
Sander and Polasky (2009) Shultz and Schmitz (2008) Sanders and Manson (2007) Lake et al.(1998) Benson et al. (1998) Wolverton (1997)	How to use Viewshed in GIS How to develop a complex DEM How to develop quantifiable views using DEM and Viewshed/Viewscore View with diminishing utility

Source: Compiled using the above papers

Methodology of creating viewability measurement variable using viewshed analysis

Viewshed is a term used to indicate the entire area that an individual observer can see from a given point. It is characterized by visibility between locations. Viewshed is a computer-intensive process, and the processing time is highly dependent on the raster resolution.[5]

Viewsheds were developed using the topographic digital elevation model (DEM) data and the building-height data for the entire city of Worcester. Finally, viewsheds were created to find which CE protected parcel is visible, what is the minimum distance from which the CE is visible, and how much of the area of the CE is visible from each of the home samples?

Sander and Manson [6] created viewsheds based on natural topography (DEM of land-elevation data) and view-impeding 1,850 built structures. The study used different methods for determining building heights--actual versus uniform heights, based on familiarity--and average heights and locations--actual footprints versus generalized locations using a buffer around the centroid of property parcel.

Lake et al. and Shulz and Schmitz [7] presented a methodology of developing viewshed using GIS in their environmental-benefit study. Their study focused on views and their economic benefits to the view-commanding surrounding properties. The viewshed analysis has been carried out using the 3-D and Spatial Analyst software in the ArcGIS 9.3.[8] Using the building footprints (polygon data) and building-heights data, a vantage point was set at six feet above the ground, and viewshed was developed that accounted for both the topographical undulation and the view-obstructing buildings (as visual barriers) that obstruct the view of CE properties from

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[5] ESRI, "Viewshed (3D Analyst)," ESRI Developers Network, Documentation Library, ESRI. Accessed from http://edndoc.esri.com/arcobjects/9.2/CPP_VB6_VBA_VCPP_Doc/shared/geoprocessing/3d_analyst_tools/viewshed_3d_analyst_.htm on April 10, 2010.

[6] Sander and Manson, "Heights and Locations," (2007): 257–270.

[7] Lake et al.,"Using GIS,"(2000): 521-541;
Lake et al., "Modeling Environmental Influences," (1998): 121-136. ;
Shultz and Schmitz, "View Shed Analyses," (2008): 224-232.

[8] Another study which used Viewshed is Yin and Hastings's study for Niagara Falls, where GIS Viewshed was used to assess the visibility. Li Yin, and Jonathan Hastings, "Capitalizing on views: Assessing visibility by using 3d visualization and GIS technologies for hotel development in the city of Niagara Falls, New York", *Journal of Urban Technology* 14, no. 3(2007): 59–82. This study examined whether it would be possible for a hotel on the US side to have views of the Niagara Falls, especially the Horseshoe Falls, if the city allowed taller buildings.

the surrounding homes. Weights are assigned to those homes that commanded views of the CE sites.[9]

There are several prerequisite steps before conducting viewshed analysis. DEM is required for viewshed calculation. I therefore created a DEM using the topographic and building-heights data. As discussed earlier, viewshed is a computer-intensive process, and the processing time is highly dependent on the raster resolution. I first chose an appropriate cell size for my raster resolution.[10]

a) Creation of DEM Raster

Before developing the DEM, it was critical to select a raster cell size and the viewshed parameters which would enable processing to be completed in a reasonable amount of time without losing the finesse of details.[11] In this research, I used the raster resolution of 10-foot by ten-foot cells, which means that each pixel on the raster is a ten-foot-by-ten-foot cell or a grid in size. All of the viewsheds were calculated at human eye level taken at 1.5 meters above the ground and assuming that the observer is located at the center of the home samples.[12]

Figure 3. Merged Raster – DEM of building heights and topographic features of the City

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[9] Ideally, Light Detection and Ranging (LIDAR) data should be used to create extremely detailed terrain models. Automated delineation of roof planes from LIDAR data would give more precise viewsheds, as it would have data on all the vertical obstructions that obstruct the view, such as building heights and tree heights. LIDAR is a remote- sensing system used to collect topographic data (Source : http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm accessed in December 2008).

[10] ESRI, "Viewshed (3D Analyst)", ESRI developers Network, Documentation Library, ESRI. Accessed from http://edndoc.esri.com/arcobjects/9.2/CPP_VB6_VBA_VCPP_Doc/shared/geoprocessing/3d_analyst_tools/viewshed_3d_analyst_.htm on April 10, 2010.

[11] Lake et al., "Using GIS," 2000.

[12] One may argue that the center of the house is not the best place to find a viewshed, as windows are placed on the edges, but in my research, for casting viewsheds and for simplicity, I have considered homes as just a point instead of a polygon.

The final DEM raster involved three steps: the creation of a topographic raster, the creation of a building-height raster, and the summation of the two rasters prepared in the first two steps to get 3-D DEM raster for the entire city as shown in the figure 3 below.

b) Creation of Topographic Raster

The raster was created in the ArcGIS Spatial Analyst. This first raster was based on the topographic data, and it is a DEM of the natural topography of the city. Contour and spot elevation data of the city of Worcester was used in creating this raster. Alternatively, a similar topographic DEM for the Worcester area could have been downloaded from the USGS website; however, to maintain accuracy and consistency, I created mine from the city's dataset.

c) Creation of Building Height Raster

In Worcester, building-height data was available for only the transacted properties. Using the average height criteria of a specific land-use type (for example, if the average SFH were 14 feet tall, all the homes in Worcester for which building heights were not available were assigned this average height), building heights were then assigned to the actual building footprint, wherever it was missing.[13] The same process was repeated for all different land-use types, such as retail, commercial and industrial land uses.

The second raster created for this research had only the building heights. Actual heights were assigned as a *z*-value to the building footprints, and a value of zero was assigned to rest of the area that included unbuilt areas, streets, roads, railways, and empty lots. On the building footprint raster, the actual building heights were assigned to the building footprint polygons obtained from the city's GIS cell wherever height data was available; average building heights were based on their use codes. Wherever there were no buildings, a zero value was assigned to the raster.

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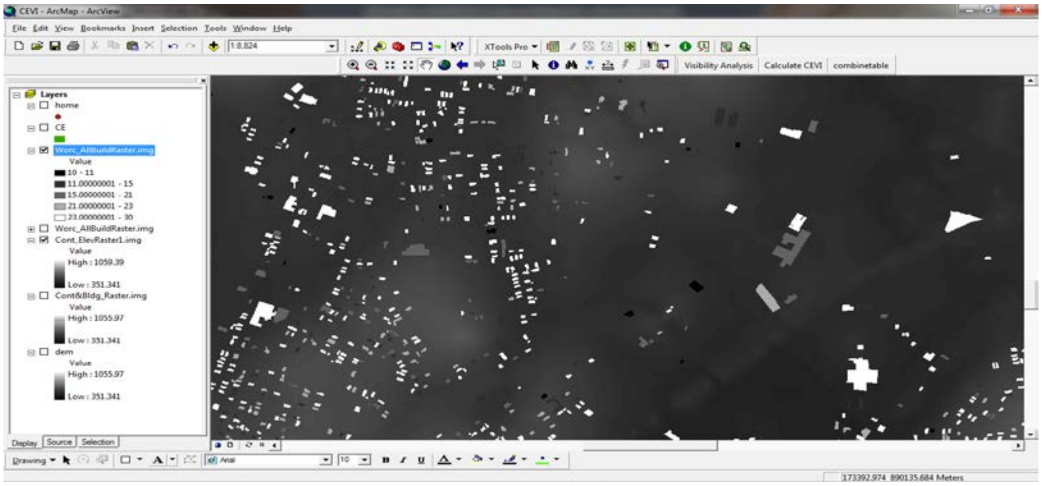
[13] Bourassa, Hoesli, and Sun, "What's in a View?" (2004): 1427-1450.

Figure 4 Building Height Raster after assigning heights to the building footprints



d) Creation of merged DEM raster - Building Height and Topographic Raster

The two rasters, the building heights raster and the topographic raster, were then merged into one combined DEM. This merged raster created a real-time 3-D model of Worcester, which displayed the city's topography and the views impeding buildings,[14] both very important for the accuracy[15] of viewshed calculation.

Section 2: Measuring Proximity

Simple logic suggests that, spatially, wherever some resource site generates any use value, the population density of its users will be higher near that site, all other things being equal. Furthermore, as users typically place a higher value on the site than the nonusers, it could be expected that the average values would decay with the increasing distance of users from that resource site.[16] This could also be understood from the first law of geography,[17] that "everything

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[14] Sander and Polasky, "Value of Views," (2009): 837–845. This study assigned the heights to the buildings based on its land use type. Data for building heights included only information for buildings with more than 7.5 square meter footprint area. The data was obtained from the County Surveyor's Office. This paper was published recently and is closer to my study in its methodology. Also, this study used a maximum view distance of 1 kilometer.

[15] I have used data on buildings but data on view-impeding trees.

[16] Ian J. Bateman et al., "The Aggregation of Environmental Benefit Values: Welfare Measures, Distance Decay and Total WTP," *Ecological Economics* 60 (2006): 450-460.

[17] Tobler (1979) as stated in Anselin, *Spatial Econometrics* 1998, 8.

is related to everything else [in geo-space], and the near things are more related than the distant things." Literature has shown how home values increase with increasing proximity to different types of amenity-generating protected open spaces and proximity has been defined in many ways in past studies. In this paper, I have used Euclidean distance.

Methodology of Squared Euclidean Distance - Home to Conservation Easements

The review has presented that proximity has been used in many ways, such as buffer rings, Euclidean distance, and driving distance. It was unclear from the literature if the distances measured were from protected-area lot boundaries to home-lot boundaries, or if distance were from the center of the protected-property parcel to the center of the home lot. This distinction is important, especially because few CE properties are large in size, and using the distance from their centers to the home centers will lead to imprecise results. In my research, the distance used is from the home parcel boundary to the CE parcel boundary, i.e., polygon boundary to polygon boundary distance. Since view is an important feature for scenic protected properties, instead of using the network or driving distance, I used Euclidean or straight line distance.

I developed Euclidean distance (in feet) and used its squared form using the Rob Chasan's[18] Visual Basic tool (VBtool) - *"MultipleMinimumDistance,"* which is available from the ESRI's tools section. This tool measures multiple distances and creates a matrix between the two polygon layers. Using this tool, I calculated distances from the lot boundary of each sample home parcel (*n*=1,238) - to the parcel boundary of all CE parcels (*n*=45).

Section 3: Measuring Visibility and Accessibility Combine - "The Conservation Easement Visibility Index (CEVI)"

Conservation Easement Visibility Index (CEVI) is a single measure that captures the effect of how visible a protected site is in terms of visible area and how much closer that visible portion of the site is from a given home sample. I would like to give due credit to my advisor, Prof. Lin Liu, who conceptualized this variable of the Conservation Easement Visibility Index (CEVI) for my

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[18] Robert Chasan, "*MultipleMinimumDistance.zip*" available from ESRI's vb script : ESRI Downloads (2003)

dissertation[19] research. CEVI is a single measure that accounts for both the accessibility and the visibility together--or, in other words, visual accessibility. The measure required measure of view and measure of distance.

CEVI, like a typical measure of accessibility, which consists of two parts: 1) a transportation element, which is usually measured by travel distance, travel time, or travel costs; and 2) the activity elements, which represent the opportunities available, usually measured as the size or importance of an activity or its attractiveness. An accessibility index is commonly specified as a gravity-type index. So, in my data sample, if I define Visual Accessibility (A) of an SFH (*i*) to the CE-protected property parcels (*j*), it is a weighted summation of squared-inverse-distance based on the size of protected properties and their inverse distances from SFH.[20] Details on similar types of indices and their use are available in Pooler,[21] Waters, Hidano, and Fik et al. In this type of index, if a home is located closer to a larger sized CE parcel, it will have a greater influence of externality generated by the CE parcels. This variable could be written as shown below:

$$A_i = \sum_{j=1}^{j} CE_{ij} / d_{ij}{}^{\lambda}$$

where A is the visual accessibility index, CE_{ij} is the attraction factor of the conservation easement-protected property defined by its area of the visible portion of the CE from the home, (or it could be any other characteristics such as size or any feature in CE that could cause attraction); d_{ij} represents the distance between SFH homes (*i*) and conservation easement protected parcel (*j*), and λ is an appropriate distance-decay exponent, typically used as $\lambda=2$. The literature does not provide enough information on what should be the value of this exponent or

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[19] Mittal, Jay. 2011. Measuring Externality Effect of Voluntarily Protected Undeveloped Properties on Surrounding Home Values: Evidence from Worcester, Massachusetts. PhD dissertation, University of Cincinnati, Ann Arbor: ProQuest/UMI, date. (Publication No. 3481322.)

[20] Pooler, "Measuring Geographical Accessibility," (1987):269-289.
Waters, "Most Beautiful Formulae," (1995:175-192.;
Noboru Hidano, *The Economic Valuation of the Environment and Public Policy: A Hedonic Approach* (Edward Elgar Publishing, 2002) 66-67.
Fik, Ling, and Mulligan, "Modeling Spatial Variation," (2003): 623-647. This paper uses location-value signatures using x-y coordinates in a spatial model.

[21] Pooler, "Measuring Geographical Accessibility," (1987): 269-289.
Waters, "Most Beautiful Formulae," (1995): 175-192
Fik et al., "Modeling Spatial Variation" (2003): 623-646.

how this value should be justified. For example, this exponent for commercial retail studies is taken λ as 2. In this research paper, I am using the exponent as λ=2.[22]

Methodology of Creating Conservation Easement Visibility Index

My advisor, Prof. Lin Liu also guided Shuyan Huo, his graduate student in the Department of Geography, to develop the algorithm for preparing the matrices that are required to compute the Conservation Easement Visibility Index (CEVI) variable in the GIS environment. Later, Shuyan Huo[23] wrote Visual Basic code to calculate the three matrices for this variable, which uses the DEM (as developed before), home samples, and CE parcel data. More detail of the methodology is presented in the next section.

The CEVI calculation involves three steps, and each step provides a matrix. The three steps are 1) calculate the visible area of each CE($_j$) parcel from each HOME($_i$); 2) calculate the shortest distance to the visible portion of each CE($_j$) parcel from each HOME($_i$), and then 3) calculate the CEVI($_i$) as a weighted index for each HOME($_i$). The three matrices include the area matrix, the distance matrix, and the CEVI matrix. The distance matrix accounts for distances of each home from each CE parcel. Similarly, the area matrix accounts for the visible area of each CE parcel from each home. To fill data in these matrices, first I created two empty database tables (*.dbf), one for the area matrix and one for the distance matrix. In each table, each row is a HOME($_i$), with MAP-ID as the identifier for homes, and each column is a CE($_j$) property parcel, with MAP-ID as the identifier for CE. Thus, an area matrix, A($_{i,j}$), and a distance matrix, d($_{i,j}$), are created.

a. *Creating Visible Area Matrix (Viewability)*

This matrix provides raster-cell areas that are visible from HOME($_i$) to CE($_j$) parcels. The first step uses the Viewshed analysis function of Arc Map 9.3 to identify the visible areas on the DEM. This function calculates the visibility for each ten-foot-by-ten-foot pixel on the DEM from one or more observer locations, based on a virtual surface. In this case, individual HOME($_i$) is the observer location, and the virtual surface is represented by a DEM raster whose pixel values are the sum of terrain elevations and building heights as explained earlier. It is a merged raster developed with topography and building-heights data.

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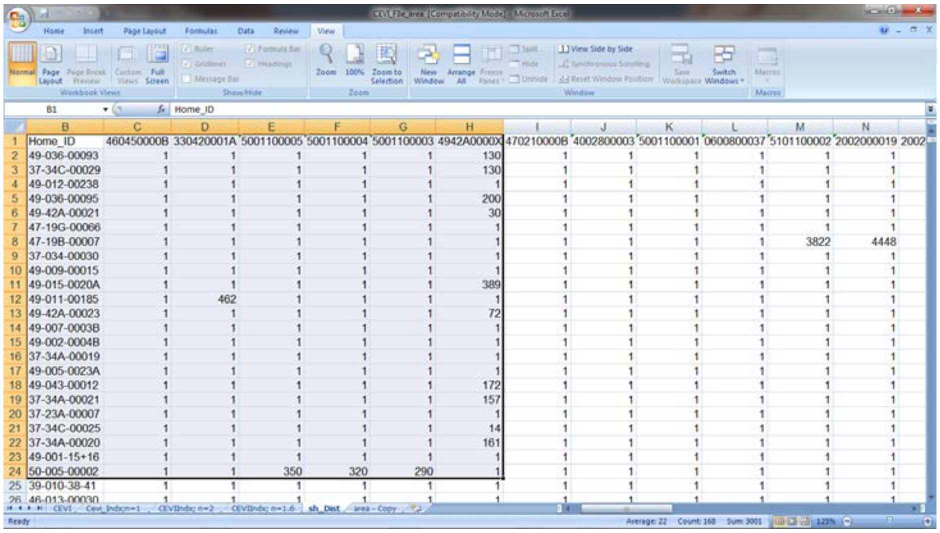
[22] I tested my model for the three different λ values of 1, 1.6 and 2 and found that all are significant; however, the model improves more if λ =2.

[23] Shuyan Huo, MA Geography, “VB script for the CEVI Index,” Department of Geography, University of Cincinnati 2009.

For each HOME($_i$), first I used the Viewshed analysis to generate an output Viewshed($_i$) raster. This output has only two possible pixel values--a value of one indicates visible and a value of zero indicates invisible. This output is then clipped. For this clipping of the Viewshed($_i$) raster by each CE($_j$) property, I extracted a smaller Viewshed($_{i,j}$) raster, which keeps only the visibility values (1 or 0) for the pixels inside CE($_j$). The number of visible pixels in the Viewshed($_{i,j}$) raster represents the visible area of CE($_j$) from HOME($_i$). This output of area calculation was saved as A($_{i,j}$) in the Area matrix.

Figure 5 Visible Area Matrix (Homes to all Visible CE Parcels)

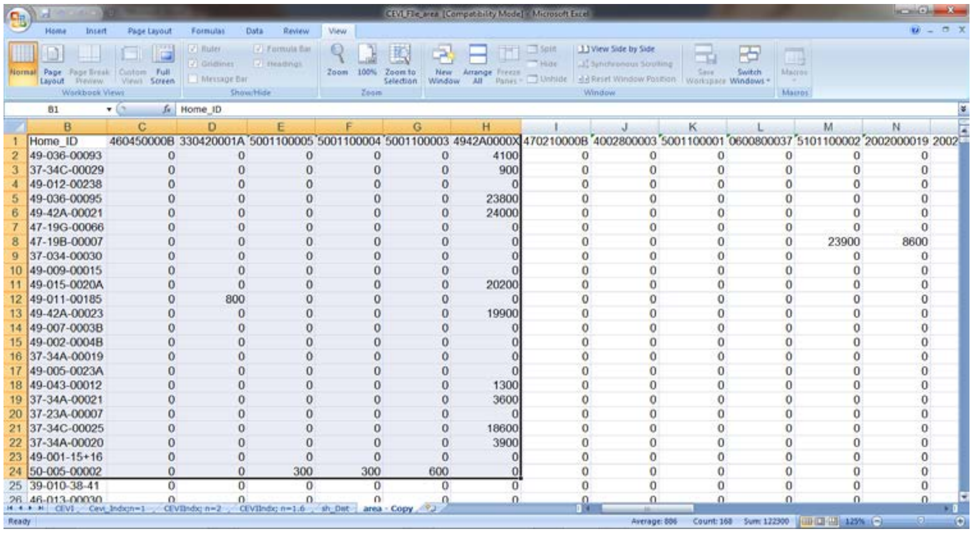


	B	C	D	E	F	G	H	I	J	K	L	M	N	
1	Home_ID	460450000B	330420001A	5001100005	5001100004	5001100003	4942A0000X	470210000B	4002800003	5001100001	0600800037	5101100002	2002000019	2002
2	49-036-00093	1	1	1	1	1	130	1	1	1	1	1	1	
3	37-34C-00029	1	1	1	1	1	130	1	1	1	1	1	1	
4	49-012-00238	1	1	1	1	1	1	1	1	1	1	1	1	
5	49-036-00095	1	1	1	1	1	200	1	1	1	1	1	1	
6	49-42A-00021	1	1	1	1	1	30	1	1	1	1	1	1	
7	47-19G-00066	1	1	1	1	1	1	1	1	1	1	1	1	
8	47-19B-00007	1	1	1	1	1	1	1	1	1	1	3822	4448	
9	37-034-00030	1	1	1	1	1	1	1	1	1	1	1	1	
10	49-009-00015	1	1	1	1	1	1	1	1	1	1	1	1	
11	49-015-0020A	1	1	1	1	1	389	1	1	1	1	1	1	
12	49-011-00185	1	462	1	1	1	1	1	1	1	1	1	1	
13	49-42A-00023	1	1	1	1	1	72	1	1	1	1	1	1	
14	49-007-0003B	1	1	1	1	1	1	1	1	1	1	1	1	
15	49-002-0004B	1	1	1	1	1	1	1	1	1	1	1	1	
16	37-34A-00019	1	1	1	1	1	1	1	1	1	1	1	1	
17	49-005-0023A	1	1	1	1	1	1	1	1	1	1	1	1	
18	49-043-00012	1	1	1	1	1	172	1	1	1	1	1	1	
19	37-34A-00021	1	1	1	1	1	157	1	1	1	1	1	1	
20	37-23A-00007	1	1	1	1	1	1	1	1	1	1	1	1	
21	37-34C-00025	1	1	1	1	1	14	1	1	1	1	1	1	
22	37-34A-00020	1	1	1	1	1	161	1	1	1	1	1	1	
23	49-001-15+16	1	1	1	1	1	1	1	1	1	1	1	1	
24	50-005-00002	1	1	350	320	290	1	1	1	1	1	1	1	
25	39-010-38-41	1	1	1	1	1	1	1	1	1	1	1	1	
26	46-013-00030	1	1	1	1	1	1	1	1	1	1	1	1	

b. Creating Shortest Distance Matrix

This is the second step. To calculate the shortest distance, the Euclidean distance function of Arc Map was employed. This function calculates a distance($_i$) raster for each HOME($_i$), whose pixel values are the Euclidean distances from each pixel to HOME($_i$). As mentioned above, the Viewshed($_{i,j}$) raster had three possible values: no value outside the CE($_j$) boundary, and a value of one for visible and a value of zero for invisible cells inside the CE($_j$). Thus, the result of Viewshed($_{i,j}$) raster-timing distance($_i$) raster will also have three possible types of values: 1) no value for outside pixels; 2) positive values for inside visible pixels, which are equal to the distance values; and 3) a value of 0 for inside invisible pixels. Thus, the smallest positive pixel value in this result raster represents the shortest distance of the visible portion of CE($_j$) to each HOME($_i$). This was saved as d($_{i,j}$) in the Distance matrix.

Figure 6 Distance Matrix of all Homes to all Visible CE Parcels



B1 Home_ID

	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Home_ID	4604500008	330420001A	5001100005	5001100004	5001100003	4942A0000X	470210000B	4002800003	5001100001	0600800037	5101100002	2002000019
2	49-036-00093	0	0	0	0	0	4100	0	0	0	0	0	0
3	37-34C-00029	0	0	0	0	0	900	0	0	0	0	0	0
4	49-012-00238	0	0	0	0	0	0	0	0	0	0	0	0
5	49-036-00095	0	0	0	0	0	23800	0	0	0	0	0	0
6	49-42A-00021	0	0	0	0	0	24000	0	0	0	0	0	0
7	47-19G-00066	0	0	0	0	0	0	0	0	0	0	0	0
8	47-19B-00007	0	0	0	0	0	0	0	0	0	0	23900	8600
9	37-034-00030	0	0	0	0	0	0	0	0	0	0	0	0
10	49-009-00015	0	0	0	0	0	0	0	0	0	0	0	0
11	49-015-0020A	0	0	0	0	0	20200	0	0	0	0	0	0
12	49-011-00185	0	800	0	0	0	0	0	0	0	0	0	0
13	49-42A-00023	0	0	0	0	0	19900	0	0	0	0	0	0
14	49-007-0003B	0	0	0	0	0	0	0	0	0	0	0	0
15	49-002-0004B	0	0	0	0	0	0	0	0	0	0	0	0
16	37-34A-00019	0	0	0	0	0	0	0	0	0	0	0	0
17	49-005-0023A	0	0	0	0	0	0	0	0	0	0	0	0
18	49-043-00012	0	0	0	0	0	1300	0	0	0	0	0	0
19	37-34A-00021	0	0	0	0	0	3600	0	0	0	0	0	0
20	37-23A-00007	0	0	0	0	0	0	0	0	0	0	0	0
21	37-34C-00025	0	0	0	0	0	18600	0	0	0	0	0	0
22	37-34A-00020	0	0	0	0	0	3900	0	0	0	0	0	0
23	49-001-15+16	0	0	0	0	0	0	0	0	0	0	0	0
24	50-005-00002	0	0	300	300	600	0	0	0	0	0	0	0
25	39-010-38-41	0	0	0	0	0	0	0	0	0	0	0	0
26	46-013-00030	0	0	0	0	0	0	0	0	0	0	0	0

c. *Creating CEVI using the Area and Distance Matrix*

This matrix is a combination of the shortest distance and the area matrix and was defined by an index value as follows:

$$CEVI_i = \sum_{j=1}^{n} A_{ij} / d_{ij}^{\beta}$$

in which (i) is the index of HOME; (j) is the index of CE; (n) is the number of CEs; and (β) is a user-input variable. Fig 6 shows how the two tables (Area and distance matrix) as shown in the figure 4 and figure 5 were used to develop the third table for CEVI. The tables were developed for different β values and CEVI was calculated. Later, a corresponding new field was added to the attribute table of HOMEs data, and calculated CEVI for different β values were saved to this field. First, I set β values at β =1, β =1.6, and then β =2.

To understand what these different β values mean, greater β value means giving higher weighting to those homes that are nearer to CE. If we use β = 2 in computing CEVI, it means that a protected parcel say, 100 feet from a home sample means (CEVI value of $1/100^2 = 1/10,000$) and receives a weight over 6 times that of a protected property at 1000 feet distance (CEVI value of $1/1,000^2 = 1/1000,000$), and a protected property at over 2000 meters distance receives almost no weight at all as the denominator is so large. So β values = 1 means that all protected property are considered equally attractive to the homeowners.[24]

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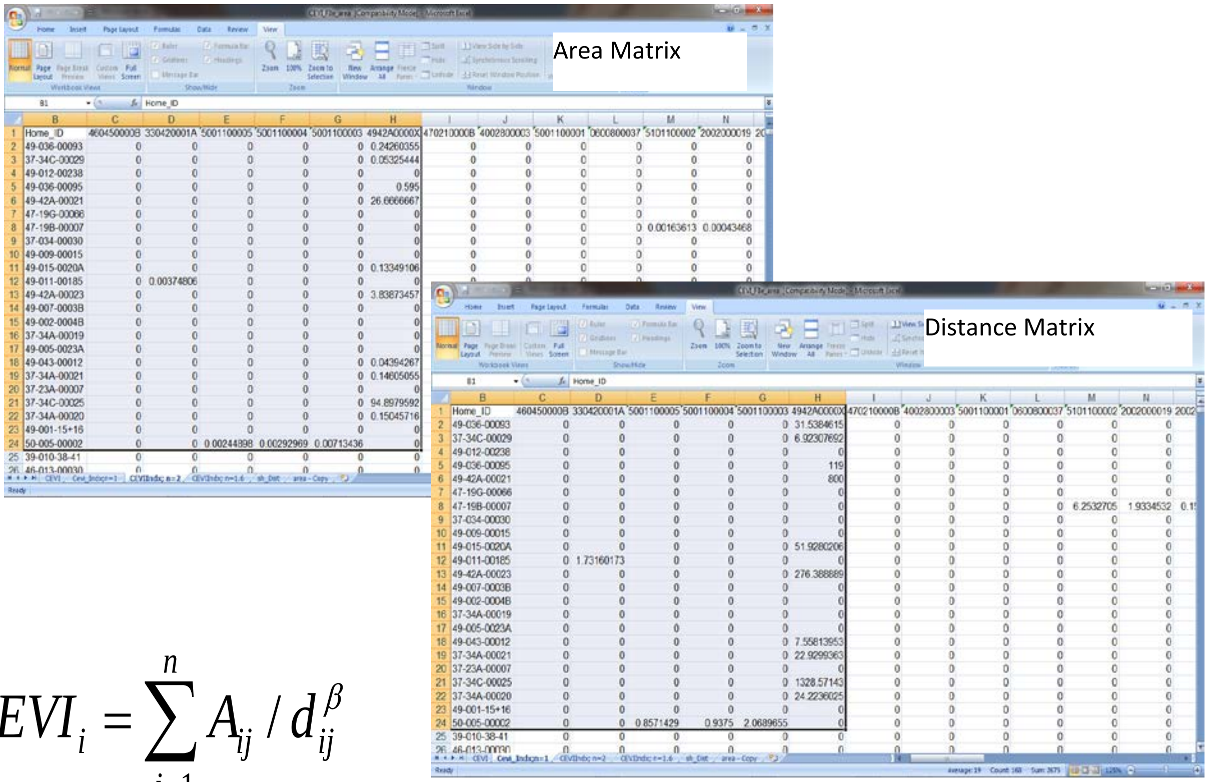
[24] Day, Bateman, and Lake, "Non Linearity in Hedonic Price Equations," (2004): 20-24.

All of the above-created externality-capturing variables have been summarized in table 2.

Figure 7 Conservation Easement Visibility Index Matrix (CEVI)



Area Matrix

	B	C	D	E	F	G	H
1	Home_ID	460450000B	330420001A	5001100005	5001100004	5001100003	4942A0000X
2	49-036-00093	0	0	0	0	0	0.24260355
3	37-34C-00029	0	0	0	0	0	0.05325444
4	49-012-00238	0	0	0	0	0	0
5	49-036-00095	0	0	0	0	0	0.595
6	49-42A-00021	0	0	0	0	0	26.6666667
7	47-19G-00066	0	0	0	0	0	0
8	47-19B-00007	0	0	0	0	0	0
9	37-034-00030	0	0	0	0	0	0
10	49-009-00015	0	0	0	0	0	0
11	49-015-0020A	0	0	0	0	0	0.13349106
12	49-011-00185	0	0.00374806	0	0	0	0
13	49-42A-00023	0	0	0	0	0	3.83873457
14	49-007-0003B	0	0	0	0	0	0
15	49-002-0004B	0	0	0	0	0	0
16	37-34A-00019	0	0	0	0	0	0
17	49-005-0023A	0	0	0	0	0	0
18	49-043-00012	0	0	0	0	0	0.04394267
19	37-34A-00021	0	0	0	0	0	0.14605055
20	37-23A-00007	0	0	0	0	0	0
21	37-34C-00025	0	0	0	0	0	94.8979592
22	37-34A-00020	0	0	0	0	0	0.15045716
23	49-001-15+16	0	0	0	0	0	0
24	50-005-00002	0	0	0.00244898	0.00292969	0.00713436	0
25	39-010-38-41	0	0	0	0	0	0

	I	J	K	L	M	N
1	470210000B	4002800003	5001100001	0600800037	5101100002	2002000019
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0.00163613	0.00043468
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0

Distance Matrix

	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Home_ID	460450000B	330420001A	5001100005	5001100004	5001100003	4942A0000X	470210000B	4002800003	5001100001	0600800037	5101100002	2002000019
2	49-036-00093	0	0	0	0	0	31.5384615	0	0	0	0	0	0
3	37-34C-00029	0	0	0	0	0	6.92307692	0	0	0	0	0	0
4	49-012-00238	0	0	0	0	0	0	0	0	0	0	0	0
5	49-036-00095	0	0	0	0	0	119	0	0	0	0	0	0
6	49-42A-00021	0	0	0	0	0	800	0	0	0	0	0	0
7	47-19G-00066	0	0	0	0	0	0	0	0	0	0	0	0
8	47-19B-00007	0	0	0	0	0	0	0	0	0	0	6.2532705	1.9334532
9	37-034-00030	0	0	0	0	0	0	0	0	0	0	0	0
10	49-009-00015	0	0	0	0	0	0	0	0	0	0	0	0
11	49-015-0020A	0	0	0	0	0	51.9280206	0	0	0	0	0	0
12	49-011-00185	0	1.73160173	0	0	0	0	0	0	0	0	0	0
13	49-42A-00023	0	0	0	0	0	276.388889	0	0	0	0	0	0
14	49-007-0003B	0	0	0	0	0	0	0	0	0	0	0	0
15	49-002-0004B	0	0	0	0	0	0	0	0	0	0	0	0
16	37-34A-00019	0	0	0	0	0	0	0	0	0	0	0	0
17	49-005-0023A	0	0	0	0	0	0	0	0	0	0	0	0
18	49-043-00012	0	0	0	0	0	7.55813953	0	0	0	0	0	0
19	37-34A-00021	0	0	0	0	0	22.9299363	0	0	0	0	0	0
20	37-23A-00007	0	0	0	0	0	0	0	0	0	0	0	0
21	37-34C-00025	0	0	0	0	0	1328.57143	0	0	0	0	0	0
22	37-34A-00020	0	0	0	0	0	24.2236025	0	0	0	0	0	0
23	49-001-15+16	0	0	0	0	0	0	0	0	0	0	0	0
24	50-005-00002	0	0	0.8571429	0.9375	2.0689655	0	0	0	0	0	0	0
25	39-010-38-41	0	0	0	0	0	0	0	0	0	0	0	0

$$CEVI_i = \sum_{j=1}^{n} A_{ij} / d_{ij}^{\beta}$$

Section 4 Externality Capturing Variables in the Final Model

There are five externality capturing variables that have been developed for this paper as discussed above. Two are the proximity measures, and the other two are viewable-area measures. Additionally an interaction variable that uses both view and proximity in a single variable is used and was expressed in an index form. Since the focus of the paper is to explain the methodology of these variables rather than describing the model itself, in this section, I will just briefly explain how the variables were used and what was found from these variables using the hedonic framework.

a. Explanation of Control and Explanatory Variables used in the model

The table 2 below presents variables used in the final model. The five externality-capturing variables as developed above are listed under the *Environmental* heading (see the last five rows of the table 2 below). The dependent variable is sale price adjusted to the house price index of Worcester at the year 2008 level. The other variables are the control variables to control for the time of the home sales, structural features of homes, and neighborhood characteristics of home where they are located.

Table 2 Explanation of final variables used for modeling including the five externality capturing variables

Variables	**Units and explanation of variables**
HPI_Sales	Dependent Variable – Home Sale Price (in $) adjusted to Worcester MSA's Housing Price Index for year 2008
Environmental	**Five Externality Capturing Variables**
View	
Tot_ViewAr	Total View area of (All CEs combined) expressed in number of visible cells - 10'x10' from home
Nr_ViewArea	View area of the nearest CE property expressed in number of visible cells - 10'x10'from home
Proximity	
DistCESq	squared Euclidean distance from the nearest CE/CR property (in ft) = 1/sq ft from home
MinDistSq	Squared Euclidean distance of the nearest visible CE property (in ft)
Combined	
Cevi_2	CEVI Index - (ViewArea / Sq m)
Home Features	**Control Variables**
Time of Sale	
Sl_2005	Homes sold in 2005 (Binary -0,1)
Sl_2006	Homes sold in 2006 (Binary -0,1)
Sl_2007	Homes sold in 2007 (Binary -0,1)
Sl_2008	Homes sold in 2008 (Binary -0,1)
Structural	
Bath	No. of Bathrooms
Qual	Assessor assigned home quality index (20 to 60)
AgeSq	Age of Home - Squared
Log_LotSf	Lot area (Sq ft) - Log transformed
Log_TULA	Total Utilizable Area (Sq ft)-Built area (Sq ft)- Log transformed
Pool	Pool Available / Not Available (Binary – No=0, Yes=1)
Garage	Garage Available / Not Available (Binary – No=0, Yes=1)
Neighborhood	
Hsg_Den	Housing Density in the neighborhood-(No. of Houses/ Acre) H001001
MdHsg_Val	Median Housing Value ($)of owner occupied houses H085001
Perc_Blac	Percentage of Afro-Americans P006003

b. Conclusions from the models

The model used was linear regression model and it took the following structural form:

$$Y_i = \beta_0 + \beta_i(\text{Structural})_i + \beta_i(\text{Neighborhood})_i + \beta_i\,(\text{Externality})_i + \varepsilon_i$$

Of the five explanatory externality capturing variables, four were found to be statistically insignificant within p <0.05, which means that those variables do not contribute any value to the model, meaning that these four variables have no role in creating home price. These were two view and the two proximity variables. The fifth variable, CEVI, which is the interaction term of visibility and distance (CEVI_2) was found to be statistically significant within alpha = 0.03 (97 percent) p <0.03 and has a positive sign, which means that this variable has a role in creating value for homes. The positive sign of the beta means that with the increase in the value of this variable, the value of the home prices will increase. This interaction effect variable--CEVI_2 variable--has the beta coefficient of Beta = 64.18, t(2.23) and p < .03. It signifies the importance of both the distance to CE parcels from homes and the visibility of CE parcels from homes together. Similarly, this also means that among the home samples chosen for the study, even though a home is abutting the CE parcel (highest level of proximity) or is just a short distance (for example, ten feet) away, if a home has zero visibility of CE parcels, the price effect on homes will be zero.

The Conservation Easement Visibility Index value for CEVI_2 for average home samples is CEVI_2 M = 3.98, SD = 35.63. For the samples, the CEVI index value ranges from 0 to 926. The beta coefficient of CEVI_2 of 64.18 means that by increasing the index value by one unit, the average home value will increase by $64.18, holding all other variables constant. This also means that for at least one home that has the highest CEVI index value of 926, in my sample of n=1,238 homes, the home price will increase by $64.18 x 926 = $59,430. The other four externality variables were found insignificant, signifying that independently proximity (distance) does not matter, and independently viewability also does not matter. The output for the rest of the four variables were Tot_ViewAr Beta=0.001, t(.14), and p < .89. Tot_ViewAr is insignificant. Similarly, another view variable called Nr_ViewArea is also found insignificant with *Beta*=-.019, t(-.98) and p < .33. This variable was intended to measure the viewable area of the nearest conservation easement parcel from homes. The insignificance of these two view variables could be explained by the fact that just viewing scenic properties is not a sufficient condition for a premium price for homes, as the scenic properties could be far away from home samples.

The proximity variable of DistCESq is insignificant, with *Beta*= 0.008, *t*(1.31) and *p* < .19. One other proximity variable was MinDistSq, which measures the minimum distance from which a conservation easement parcel is visible. The MinDistSq was also found insignificant, with *Beta*= -4.68E-022, *t*(-.22), and *p* < .83. This can be explained in two ways: first, consider a case where home samples are abutting conservation easement parcels, but the homes have a total visual disconnect with the scenic conservation easement parcels. Alternatively, if homes have low accessibility to the abutting scenic parcels, the proximity of conservation easement parcels has a very low value for homeowners. The second explanation, which is more relevant for the MinDistSq variable because the view to conservation easement parcels exists, is the potential lack of knowledge and lack of recognition of the presence of conservation easements among the homeowners.

Conclusion

This paper was aimed to present the GIS based methodology of creating the CEVi index, more specifically developing the automated process of view measurement and then using the same to develop the CEVI index. Later, this paper used a simple linear model outcome as an example to demonstrate the usefulness of the combined measure of proximity and view together. The high significance p<.03 of the interaction CEVI variable suggests that combining the two independent variables of viewability and proximity is more relevant. The findings of this model are important, as they partially answer one research question: As revealed in the capitalized home prices, how many externality benefits do the conservation easement protected-properties externalize on their surroundings, due to homes' proximity to and visibility of conservation easement parcels?

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