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Economic analysis of poorly sited septic systems: a hedonic pricing approach

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Erratum

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In the article 'Economic analysis of poorly sited septic systems: a hedonic pricing approach', first published online in the *Journal of Environmental Planning and Management* on 11 September 2012, in the first paragraph of Section 2, the two sentences starting with 'This number is higher…' and ending before 'The failure of septic systems … ' are incorrect.

The two sentences should read as follows:

The number of replacement and alteration systems constitutes 30% of the total installed systems during the period 1 July 2007 to 30 November 2007. This number is higher than previous studies showing estimated failure rates of 13-20% (Tumeo and Newland 2009), 20-25% (Maumee River Remedial Action Plan 2004), and 27% (Mancl 1990, Ohio Environmental Protection Agency 1995).

The Editors and Publishers would like to apologise for this error.

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Economic analysis of poorly sited septic systems: a hedonic pricing approach

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Proper design and quality of soil play an important role in the functioning of soil-based septic systems. Septic systems with traditional leach fields are not suitable for treatment of domestic wastewater in Ohio due to shallow soils. Along with other adverse health effects, untreated or partially treated wastewater could lead to a loss of property valuation. The assessed value of 549 randomly selected properties in Licking County, Ohio was analysed using hedonic pricing method to isolate the effect of poor site selection on the value of the properties. Results indicate that properties sited on soils that are deemed optimal for wastewater treatment are valued 6.2% to 6.8% higher than those sited on sub-optimal soils. The results from this study can help the property owners in making better private decisions regarding installation of septic systems, but can also guide policy decisions that affect public health and common waters.

Keywords: septic systems; soil quality; property valuation; hedonic pricing method

1. Introduction

Soil-based septic systems serve between 20–25% of the households in the United States (US Census Bureau 2007, USEPA 2008). Soil recommendations developed at The Ohio State University suggest a minimum depth of 4 ft (1.22 m) of deep, permeable and unsaturated soil to obtain complete removal of pollutants. In a well-functioning septic system, 4 ft (1.22 m) of soil can remove pollutants such as suspended solids, organic matter, bacteria, ammonia and viruses (Mancl and Slater 2001). However, only 6.4% of the soils in Ohio are deeper than 4 ft (1.22 m) and suitable for traditional leach field systems. Advanced systems such as mound, media filter, aerobic lagoons, disinfection systems, etc. augment the treatment capabilities of natural soils, such that only 2 ft (0.61 m) of soil or less is needed to achieve complete removal of pollutants. However, the high cost of installation and maintenance of these advanced systems, along with lack of strict standards in Ohio counties (Ohio Administrative Code 1977) have made leach field systems the

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default choice in an overwhelming majority of rural Ohio households (Vedachalam *et al*. forthcoming). The Ohio Department of Health notes that Ohio has the oldest sewage rules in the United States. Several alternative technologies have been developed and improved in the last 30 years, starting with the mound system developed by Converse and Tyler (1985) at the University of Wisconsin for installation in areas with shallow soil depths. Also called the Wisconsin mound for its place of origin, this technique used a layer of sand placed above natural soil to augment its treatment capacity. This paper investigates the economic cost of siting septic systems on incompatible soils.

2. Septic systems failure

Approximately 25% of Ohio's households are served by some type of sewage system located on the property, with an estimated 1 million systems in use today. Seasonal saturation in the soils and the presence of bedrock represent conditions that do not allow for the treatment of wastewater necessary to keep communities safe (Ohio Department of Health 2008). This number is higher than previous studies showing estimated failure rates of 13–20% (Tumeo and Newland 2009), 20–25% (Maumee River Remedial Action Plan 2004), and 27% (Mancl 1990, Ohio Environmental Protection Agency 1995). This number matches the state-wide failure rate of septic systems reported in earlier studies 27% (Mancl 1990, Ohio Environmental Protection Agency 1995), 20–25% (Maumee River Remedial Action Plan 2004), and 13–20% (Tumeo and Newland 2009). The failure of septic systems has been attributed to various reasons, primary among them being inadequate soil quality, under-design, age of the system (DeWalle 1981, Mancl and Slater 2000), and failure to remove excess sludge from the septic tank (Mancl and Slater 2000).

2.1. Impacts of failure

Installation of leach field systems in shallow and saturated soils leads to incomplete treatment and discharge of pollutants. The resulting effects could be contamination of ground and surface water with micro-organisms, surfacing effluents and odours. Untreated waste discharged to shallow soils travels vertically through the unsaturated zone and contaminates groundwater. Once in groundwater, bacteria and viruses are transported long distances in a short period of time (Minnesota Pollution Control Agency 1999). Partially treated wastewater discharged into saturated soils can lead to run-off of nutrients such as phosphorus into nearby lakes and streams. Consumption of contaminated groundwater or contact with contaminated soil or run-off water presents potential health risks for humans, pets and wildlife (USEPA 2000).

Various studies have shown contamination of groundwater by malfunctioning septic systems. Arnade (1999) tested drinking water for faecal coliforms, nitrates and phosphates from residential wells in Palm Bay, Florida and found that samples collected during the wet season contained significantly higher concentrations of microbial and inorganic pollutants compared with samples collected in the dry season. A statistically strong correlation was also established between decreasing distance between wells and septic tanks and increasing pollutant concentration in the drinking water. DeBorde *et al*. (1998) identified coliphage at high concentrations in both septic tank effluents and the underlying groundwater in a test conducted at a high school located in western Montana. Yates (1985) reviewed several studies that identified correlation between density of septic systems and contamination of groundwater, a result that was corroborated by Borchardt *et al*. (2003). The review by Yates (1985) also documents several studies that traced outbreaks of Hepatitis A, typhoid and gastroenteritis to contamination of groundwater from septic tank effluent. Septic systems density was also associated with endemic diarrhoeal illness in children (Borchardt *et al.* 2003). The massive gastrointestinal outbreak in South Bass Island, Ohio, in 2004 was traced to the contamination of groundwater through septic tanks and other wastewater treatment facilities (Fong *et al*. 2007).

2.2. Private costs

Large-scale system failures may result in enforcement action from the Environmental Protection Agency. Records from Ohio EPA show that during the period 1986–2007, over 240 communities were under enforcement or had been identified as having significant impacts from failing systems (Ohio Department of Health, 2008). However, the costs of failing systems are difficult to measure, especially at the individual level. Other than the negative health effects and the resulting cost of illness leading to a decrease in the quality of life, an individual may also encounter higher maintenance and repair costs in the case of poorly designed systems, and a loss of property valuation.

This study aims to isolate the effect of poor site selection and design on the value of the property. The authors are aware of no similar study undertaken so far. Hence, as much as these results cannot be benchmarked against previous studies, this study opens up new ways of improving the quality of wastewater treatment in rural communities.

3. Study area

This study was conducted in Licking County, Ohio (see Figure 1). Licking County is bordered by Franklin County – which includes the state's largest city and capital, Columbus – in the west. The county seat, Newark, is located approximately 32 miles (51 km) east of Columbus. Being a suburban county, Licking County's racial composition is different from that of the state. However, Licking County is comparable to the state on other socio-economic indicators. The median value of a housing unit ($110,700) and median household income ($44,124) in Licking County are marginally higher than the state-wide figures of $103,700 and $40,956, respectively, while the percentage of residents with a Bachelor's degree or higher (18.4%) and population below 200% of poverty level (22.5%) are lower than the state average figures of 21.1% and 26.4%, respectively. The median age of the residents in the county (36.6 years) matches the state average of 36.2 years. Licking County's population is 158,488 and there are 58,760 households (Ohio Department of Development, 2009). Approximately 22,000 households use onsite systems for wastewater treatment.

4. Methods

In 2007, Licking County Health Department conducted a survey of households using onsite treatment systems and collected key information. Licking County Health

Figure 1. A map of Ohio counties with Licking County highlighted (inset: location of Ohio highlighted in a map of mainland US).

Department randomly selected 800 households out of the approximately 22,000 households using onsite systems in the county. The selection was made such that as many soil types as possible were covered throughout the county (Ebel 2009). The survey contained information such as the parcel code of the property lot, the type of soil, presence of curtain drains, GPS readings of the onsite systems, date of their installation and visual observations of the treatment system and its surroundings. Of the 800 households, 616 households use soil-based septic systems, while 184 households use aerator treatment systems. Since the aerator systems utilise mechanical equipments, their performance is not affected by the quality of soil. Hence these households were not included in this study. Households that did not contain information on the type of soil or could not be located on the county auditor's records were removed from the study, as were households categorised as agricultural properties by the county auditor. The remaining 549 residential properties were analysed further as part of the study. The distribution of the households according to the soil categories (discussed below) did not change significantly ($\chi^2 = 1.66$, $p > 0.6$) when the sample size was reduced from 800 to 549. Figure 2 shows the 549 properties selected for the study on a map of Licking County.

Mancl and Slater (2002) categorised the soils found in Ohio in four categories, depending on their ability to remove pollutants such as suspended solids, ammonia, organic matter, bacteria and viruses from domestic wastewater. Based on the depth of these soils from the bottom of a sewage leaching trench to a limiting condition, they are:

(1) Soils up to 4 ft (1.22 m) deep, suitable for leach fields;
(2) Soils up to 2 ft (0.61 m) deep, suitable for mound systems;
(3) Soils up to 1 ft (0.31 m) deep, suitable for irrigation of treated wastewater; and
(4) Soils less than 1 ft (0.31 m) deep, not suitable for onsite systems.

Table 1 shows the distribution of these soils across Ohio, in Licking County and in the sample selected for the study. It can be seen that Licking County has higher percentages of soils suitable for leach fields and mound systems than the average soils in Ohio. A significantly higher proportion of residents in the sample purchased or built houses in soils suitable for either leach fields or mound systems compared to the average percentage of soils found in the county.

Apart from the soil type, the survey collected information on whether the septic system also included a curtain drain, an artificially drained septic system that lowers the water table and carries the waste stream away from the property. The date of installation of the septic systems was also recorded in the survey. Licking County Health Department did not have records of septic systems installed before 1976. As a result, properties missing information on the installation date for septic systems were given a default installation date of 1 January 1976.

All properties are issued a unique parcel identification number by the county. This parcel number was then entered in the online property management database of Licking County and specific information on each property such as size of the lot, age of the property, number of bedrooms and bathrooms, etc. was obtained, along with the history of sale/transfers and the assessed price as on 1 January 2008. Although sale price is a better indicator of market behaviour, only 189 of the 549 properties

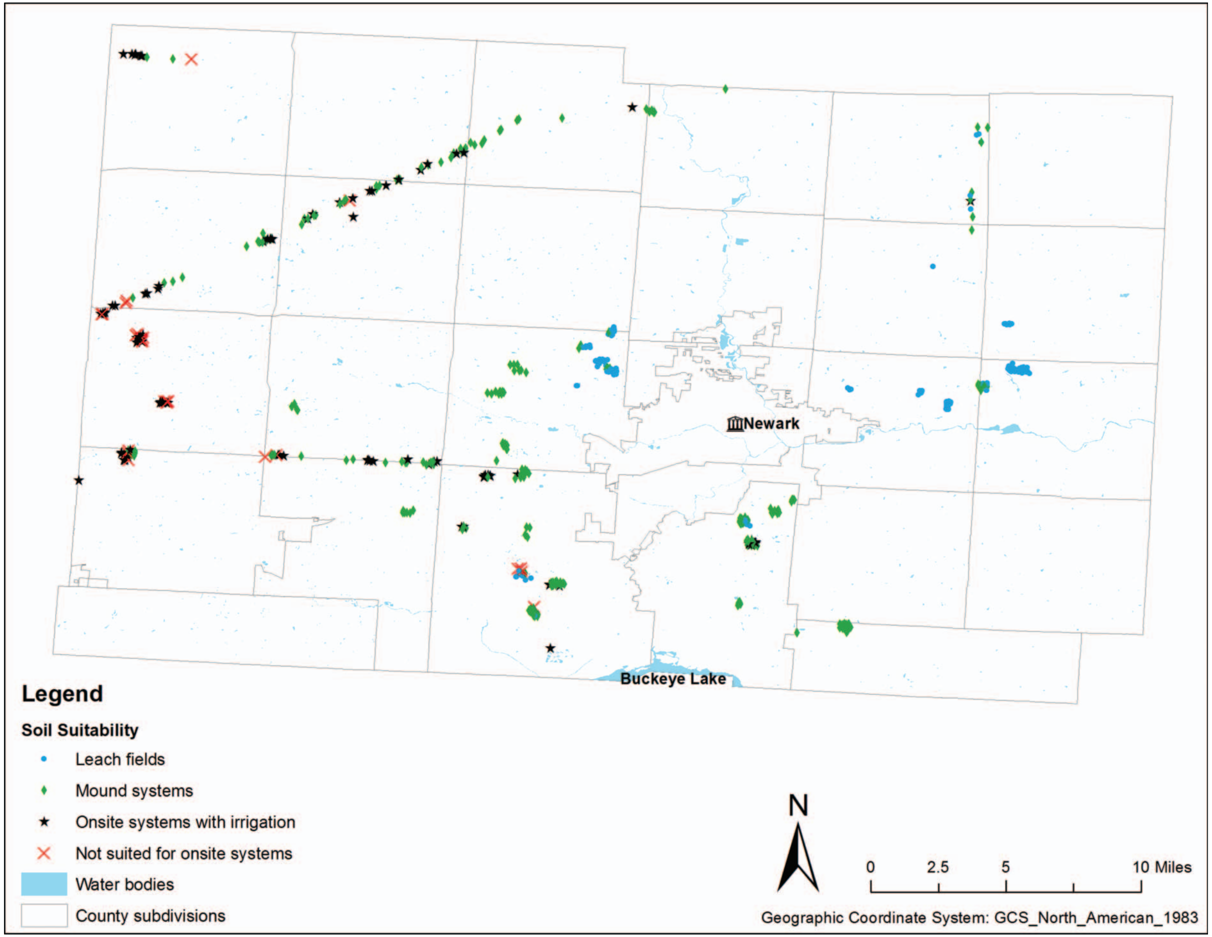

Figure 2. A map of Licking County showing the 549 properties based on the suitability of soils for various onsite systems. (Colour version online.)

Table 1. Distribution of soils based on their ability to treat wastewater.

Region	Percentage of soil suitability			
	Leach fields	Mound systems	Onsite treatment with irrigation	Not suited for onsite systems
Ohio[a]	6.4	25.4	49.1	19.1
Licking County[a]	16.3	38.2	33.8	11.7
Sample	29.3	48.6	17.3	4.7

Source: [a]Mancl and Slater (2002).

had sales records in the county auditor's database. In cases such as this, it is common practice to use the assessed value instead (Bin *et al*. 2007, Ryan and Weber 2007), in spite of its shortcomings (Harris 2004, Hoyt and Garen 2005, Smith 2007, Hoyt *et al*. 2011). Assessed value was used in the analysis since it was highly correlated with the limited sale price data ($R^2 = 0.947$) and allowed the use of all 549 properties.

In Ohio, the primary responsibility for property appraisal and assessment rests with 88 county auditors, who are elected to four-year terms. County auditors are compensated for real estate assessment services based on a percentage of the property tax revenues generated. Each county has a county board of revision, responsible for assuring that all properties in the county are listed and valued appropriately, and at the required state-wide level of assessment. In Ohio, both the state and the county have a role in equalising property values to assure that properties are assessed at a single state-wide level of assessment (35% of current true value). In addition, the statute requires that properties are inspected and valued every six years, and their values updated every three years. Before the study period in this paper, Licking County last underwent a re-appraisal in 2005, followed by an update in 2008. When a property is reassessed by the county, the replacement cost of buildings, structures and improvements to land is based on prices prevailing during the year prior to the one in which the reassessment becomes effective for tax purposes. The work of county auditors and county boards of revision is overseen by the Ohio Department of Taxation's tax commissioner.

Licking County has 26 townships, of which 20 are zoned. The zoning status of the township was included in the model, as was the quality of the school districts in the county. Licking County has 11 school districts, including one that is primarily based in the neighbouring Knox County. The Ohio Department of Education (2007) issues an annual report card, where school districts across the state are measured on various parameters including a 'Performance Index Score', which is the weighted average of the school districts' assessment results across all tested grades and all subjects. The Performance Index Score is a comprehensive measure of school quality, publicly available to residents and non-residents, and is reflected well in the housing prices (Seo and Simons 2009). Additional information such as distance to nearby urban centres such as the state capital Columbus (Franklin County) and Newark (county seat and the largest city in Licking County) was calculated using the ArcGIS software and added to the model to account for property valuations influenced by proximity to these locations. The data were analysed using the SPSS and Stata software packages. The raw data is available in Vedachalam (2011).

5. Hedonic pricing method

Environmental economists have used non-market valuation techniques to identify the benefits of environmental attributes that do not have a market value of their own, such as air and water quality (Cangelosi *et al.* 2001). One of the methods to value environmental attributes is hedonic pricing method. Although used for a variety of applications, from measuring the technological change in automobile technology (Saviotti 1985) to estimating the price of wine (Combris *et al.* 2003), hedonic pricing method has been extensively used in the field of environmental economics to measure the impacts of urban stream restoration (Streiner and Loomis 1995) and countryside characteristics such as woodlands and marshes (Garrod and Willis 1999), and changes in property values due to improvements in river water quality in a neighbourhood (Hitzhusen 2007). Hedonic pricing method measures the price differentials that arise due to quality differences across similar goods. Hedonic pricing uses the different characteristics of a traded good, such as real estate, to estimate the value of a non-traded good, such as water or soil quality (Hitzhusen *et al.* 1999). By correcting and/or controlling for other factors that would infiuence the value of a particular property, it is possible to isolate the hidden value of the amenity, in this case the value of a well-sited septic system. The price of a residential property P is explained by a hedonic function:

$$P_i = f(S_i, C_i, Q_i) \tag{1}$$

where S_i represents the structural characteristics, C_i represents the community characteristics and Q_i represents the environmental characteristics. Structural characteristics of a property include physical attributes such as size of the plot, age, number of rooms, etc. Other things being equal, it is expected that an additional bathroom or bedroom represents an extra amenity. Community characteristics include distance to nearby urban and recreational centres, zoning status of the township and quality of the school district. Zoning protects neighbourhood residents from externalities arising out of unfavourable land-use. By preventing undesirable uses, zoning is beneficial to the residents and therefore is expected to increase the value of the property. School district performance is expected to be positively correlated with price. Environmental characteristics include presence of curtain drains and the type of soil (a detailed description follows in the next section). In a study conducted on the Muskingum River corridor, Hitzhusen *et al.* (2000) found that presence of septic tank significantly affected the price of a property, and its contribution was \$247 in 1999 (0.54% of the assessed value). Although no previous studies have shown the impact of soil quality on the property value, studies on contamination of municipal water and groundwater could yield some powerful insights. Des Rosiers *et al.* (1999) reported that the average duration of boil-water advisories negatively impacted the property values in a municipality affected by water-quality problems in Quebec, Canada by as much as 5.2% to 10.3% of the average sale price. Simons and Saginor (2006) conducted a meta-analysis of 58 peer-reviewed articles that measured the impact of environmental contamination on property values, and reported that groundwater contamination diminished the average property value by 10.5%. Kilpatrick (2006) studied the impact of perchlorate contamination in a neighbourhood in southern California, and concluded that properties affected by the contamination were valued 21.82% lower than typical unimpaired properties in the year following the contamination. Based on the available literature, soils less suitable for onsite systems are expected to result in a reduced valuation of the property. Housing prices are also affected by the prices of nearby properties, hence Equation (1) should include a variable that captures that effect. The inclusion of a spatial lag of the dependent variable accounts for unobserved neighbourhood effects and other potentially omitted spatial variables. Similar to the approach suggested by Carruthers and Clark (2010), the spatial lag in this model is the average value of the three nearest properties. Since the spatial lag is endogenous to the market value in the hedonic model, ordinary least squares (OLS) cannot be used to estimate the function. Instead, spatial two-stage least squares (S2SLS) developed by Kelejian and Prucha (1998) is used to yield efficient, unbiased estimates of the variables.

6. Data

The type of soil was defined as a categorical variable, where each type of soil was listed as a separate category. As described in the Methods section, the soils were categorised as those suitable for leach fields (LEACH), mound systems (MOUND), onsite systems with irrigation (IRRIG), and those unsuitable for any onsite systems (UNSTL), and were indicated by respective binary variables (1 indicating presence, and 0 indicating absence). Using this method, three of the categories entered the model, while the fourth category served as the reference. The reference variable was rotated amongst the four categories, until all possible variations of the model were run. For better visualisation of the results, the variable IRRIG was used as the reference variable, and the other three types of soil (LEACH, MOUND and UNSTL) entered the model. The presence of curtain drain (DRAIN) was also indicated by a binary variable (1 indicating presence, and 0 indicating absence).

Structural characteristics such as living area (AREA), number of bathrooms (BATH) and bedrooms (BDRM), age of the property (AGEP) and age of the septic system (AGES), along with the dependent variable – assessed price (ASSESS) – were expressed in logarithmic form. The zoning status of the townships (ZONE) was indicated by a binary variable. Quality of the school district (SDIST), and distances to Columbus (COLS) and Newark (NWRK) were continuous variables, but expressed in linear form. Plot size (PLOT), a commonly used variable in hedonic models could not be used due to several missing values from the County Auditor records. The variables are defined and statistical measures presented in Table 2.

7. Results

Results from both the OLS and S2SLS models are presented in Table 3. Regression diagnostics determine the appropriateness of the model specification. Multicollinearity was tested using the variance inflation factor (VIF). Typically, high values of VIF indicate multicollinearity. In the above analysis, distance to Newark (NWRK) displayed a VIF more than 10, possibly due to correlation with distance to Columbus (COLS). NWRK was subsequently removed from the model. The R^2 for the OLS model is 0.789, indicating that the model explains 78.9% of the cross-sectional variation in the assessed value of the properties. Autocorrelation was tested using the Durbin-Watson statistic. D-W score ranges from 0 to 4 with a score of 2 indicating zero autocorrelation. The S2SLS model resulted in a D-W score of 1.95,

Table 2. Variable definitions and statistics.

Variable	Description	Min	Max	Mean	Std. dev.
ASSESS	Assessed price of the property ($)	31,300	998,900	208,093	118,849.2
PLOT	Plot size (acres)	0.431	29.89	3.76	3.94
AREA	Built area (sq. ft.)	720	5935	2045.13	840.31
BATHS	Number of full bathrooms	1	5	1.93	0.69
BDRM	Number of bedrooms	0	6	3.30	0.63
FIRE	Number of fireplaces	0	6	0.56	0.60
AGEP	Age of the property (years)	3	163	29.29	23.04
AGES	Age of the septic system (years)	5.03	32.02	22.63	10.17
COLS	Distance to Columbus (miles)	10.84	42.87	25.59	7.27
NWRK	Distance to Newark (miles)	3.15	23.29	8.98	4.53
ZONE	Dummy variable for the property located in a zoned township	0	1	0.84	0.37
SDIST	School district performance index	92.5	104.7	97.38	3.92
DRAIN	Dummy variable for presence of curtain drain	0	1	0.30	0.46
LEACH	Dummy variable for soil suitable for leach fields	0	1	0.29	0.46
MOUND	Dummy variable for soil suitable for mound systems	0	1	0.49	0.50
IRRIG	Dummy variable for soil suitable for onsite treatment with irrigation	0	1	0.17	0.38
UNSTL	Dummy variable for soil not suitable for any onsite system	0	1	0.05	0.21

Table 3. Hedonic price grading estimates.

	OLS				S2SLS			
Variable	β	S.E.	*t*-value	*p*-value	β	S.E.	*t*-value	*p*-value
(CONST)	−0.838	.378	−2.22	.027	−1.494	.393	−3.80	0.000
SPLAG					0.237	0.042	5.71	0.000
AREA	0.610	0.061	9.91	0.000	0.522	0.059	8.72	0.000
BATHS	0.101	0.018	5.41	0.000	0.098	0.018	5.44	0.000
BDRM	−0.005	0.024	−0.23	0.822	0.003	0.024	0.11	0.915
FIRE	0.044	0.024	1.84	0.066	0.046	0.024	1.90	0.058
AGEP	−0.214	0.023	−9.38	0.000	−0.161	0.025	−6.40	0.000
AGES	−0.001	0.026	−0.05	0.960	0.006	0.025	0.25	0.804
COLS	−0.008	0.003	−2.99	0.003	−0.004	0.003	−1.49	0.138
ZONE	0.035	0.047	0.76	0.445	0.029	0.047	0.61	0.539
SDIST	0.020	0.003	6.87	0.000	0.013	0.003	4.03	0.000
DRAIN	0.030	0.031	2.95	0.003	0.014	0.029	0.47	0.642
LEACH	0.120	0.040	3.00	0.003	0.074	0.039	1.85	0.065
MOUND	0.094	0.032	2.95	0.003	0.068	0.031	2.17	0.031
UNSTL	0.044	0.045	0.98	0.328	0.049	0.043	1.17	0.242
R^2	0.789				0.802			

Note: Dependent variable: ASSESS. Reference category: IRRIG.

indicating minimal autocorrelation. The right hand panel of Table 3 shows the S2SLS estimates, where the spatial lag of the dependent variable is positive and highly significant, indicating that assessed value of a property is influenced by the value of proximate properties. The inclusion of the autoregressive term in the model raises the R^2 to 0.802. Since the S2SLS model has a higher explanatory power and accounts for unexplained neighbourhood effects due to the spatial lag term, its results will be used for further analysis. The functional form was tested for heteroskedasticity using the Breusch-Pagan/Cook-Weisberg test, which was determined to be not significant ($p = 0.45$).

The final form of the hedonic function is as expressed below:

$$\begin{aligned}\ln(\mathrm{ASSESS}) &= -1.494 + 0.237 * \ln(SPLAG) + 0.522 * \ln(AREA) + 0.098 * BATHS \\ &\quad + 0.046 * FIRE - 0.161 * \ln(AGEP) + 0.013 * SDIST + 0.074 * LEACH \\ &\quad + 0.068 * MOUND \end{aligned} \tag{2}$$

At the 5% level of significance, the following variables were significantly different from zero and had a positive impact on the property valuation: spatial lag of the market value (SPLAG), living area in square feet (AREA), number of bathrooms (BATHS), school district performance index (SDIST), and soils suitable for mound systems (MOUND). Age of the property in years (AGEP) was significantly different from zero at the 5% level of significance and had a negative impact on the property valuation.

Number of fireplaces (FIRE) and soils suitable for leach fields (LEACH) were positive and significant at the 10% level. Variables such as number of bedrooms (BDRM), zoning status of the township (ZONE), presence of curtain drain (DRAIN), age of the septic system in years (AGES), distance to Columbus in miles (COLS), and soils not suitable for any onsite systems (UNSTL) were not significant in this model. When compared to the OLS model, the significance of three variables was diminished in the S2SLS model – LEACH is significant at 10% (as compared to significance at 5% in OLS), while DRAIN and COLS are not significant. All three are spatial variables, and the inclusion of the spatial lag term likely diminished the effect of those variables.

8. Discussion

From the authors' perspective, the key variables in this model were the type of soil, presence of curtain drain and the age of the septic system. While the classification of soils based on their ability to treat wastewater forms the hypothesis for this study, curtain drains are relevant due to their unique role in wastewater treatment. Curtain drains are used in areas with shallow soils to avoid interaction between untreated wastewater and groundwater. Although curtain drains impose a negative social externality since the wastewater does not get fully treated but merely moved across underneath the soil, homeowners benefit from their use since the wastewater no longer remains on their property. The use of curtain drains has become popular in recent years. Of the 116 properties in the sample built in the last 10 years, 65% of them installed curtain drains. In the sample, the median age of properties using curtain drains is 11 years (S.D. = 19.32 years), compared to 34 years (S.D. = 34.57 years) for those not using curtain drains. Therefore, it was expected that presence of curtain drains would have a positive impact on the property value. The variable was significant in the OLS model, but not in the S2SLS model.

Most septic systems are designed to last 30 years, when used at design load (wastewater volume, nutrient loading, etc.) and with regular maintenance. However, most homeowners do not replace or repair septic systems until the systems fail completely. Septic systems may be tested at the time of transfer of property or when the county health department conducts inspections based on complaints from either the homeowner or the community. In the hedonic model, age of the septic system was not a significant variable. One possible explanation is that Licking County Health Department does not have records of septic systems installed before 1976. For systems installed before 1976, the installation date was assumed to be 1 January 1976, which may not have accurately represented the real installation date of such systems. Due to weak reliability of the septic system age, the age of the property (median age = 28 years, S.D. = 23 years) is used to draw some inferences. The coefficient for property age is negative and significant. Since age is modelled logarithmically, its coefficient in the model represents a percentage change in the price due to a percent change in age, i.e. there is a 0.161% decrease in the property's price for every 1% increase in age, other things remaining same. The marginal implicit price of age was calculated as $1,146.67, based on the assessed value of the average house, $208,092. Although property age displayed weak correlation with the available data for septic system age, it can be hypothesised that older infrastructure has a negative impact on the property value.

The three variables describing soil type that entered the model were soils suitable for leach fields (LEACH), mound systems (MOUND) and those unsuitable for any onsite systems (UNSTL), while soils suitable for onsite systems with irrigation (IRRIG) was the reference variable. The variable for soils unsuitable for any onsite systems (UNSTL) was not significant in the model, indicating that there is no significant difference in the price of the properties sited on either IRRIG or UNSTL soils. Variables for soils suitable for leach fields and mound systems were, however, significant and positive. The marginal implicit price for LEACH and MOUND soils was calculated to be $14,062 and $12,897, respectively. This implies that properties sited on soils suitable for leach fields and mound systems are priced respectively $14,062 and $12,897 higher than properties sited on soils suitable for onsite systems with irrigation or those not suitable for onsite systems at all, constituting a premium of 6.8% to 6.2% for such properties. These price differences approximate the estimates provided by the Ohio Department of Health for the cost of installing a drip irrigation system and a mound system, respectively. The average estimated cost of installing a drip irrigation system is $19,750, while that for a mound system is $14,150 (Ohio Department of Health 2008). A recent news report about a proposed sewer project near Pataskala subdivision in Licking County estimated that homeowners are likely to pay $14,400 to connect to the sewer system (Jarman 2011). This analysis shows that homeowners with septic systems on shallow soils have an incentive to adopt advanced treatment systems, and carry out regular maintenance of septic tanks.

9. Policy, planning and management implications

According to the current state regulations, testing of soil samples by an approved soil scientist prior to installation of a septic system is not mandatory. As a result, designers and installers of septic systems have little oversight regarding selection of the location and the type of septic system. Therefore, quality of soil at the location of the septic system is unknown, until a targeted survey such as the one done by Licking

County Health Department is conducted. This study shows that knowledge of soil quality can be an important indicator of the performance of the septic system and consequently the value of the property. In June 2010, Sub. S.B. 110 was passed by the Ohio Senate and House of Representatives, and signed into law on 18 June 2010. The law came into effect on 17 September 2010 and requires that new state-wide rules be drafted to replace the 1977 sewage rules, and adopted no sooner than 1 January 2012. It is expected that the proposed new rules will include mandatory testing of soil quality by certified pedologists.

Another interesting observation from the data is that most of the newer properties are being built on soils that are deemed 'sub-optimal' for onsite treatment, i.e. soils that are not suitable for either leach fields or mound systems. The median age and standard deviation of properties built on the different types of soils is given in Table 4. Once prime lands in urban and suburban areas were used for public and private construction, newer development spread to rural areas with soils well suited for agriculture, but not for siting soil-based septic systems. The inability to site well-functioning septic systems in some of those soils probably did not factor in the decision-making process of potential property buyers since such information is not readily available. Availability of the soil information is likely to result in informed decisions and planned development.

Chapter 5302-30 of the Ohio Revised Code (2005) and Chapter 1301:5-6-10 of the Ohio Administrative Code (2008) require a residential disclosure form for all property transfers, except in certain special circumstances. According to this provision, the seller of the property is required to provide information related to the source of water supply, nature of the sewer system, condition of the property structure, the presence of hazardous materials and indicate any known defects in the property in good faith. The latest version of the form issued by the Ohio Department of Commerce on 6 November 2008 requires the seller to indicate the type of sewer system servicing the property. Options include public sewer, private sewer, septic tank, leach field, aeration tank, filtration bed, unknown and other. In addition, the seller is required to provide information on any leaks, backups or maintenance problems with the sewer system, and any repairs completed in the last five years. In the case of decentralised systems such as leach fields, the seller is also required to provide the date of last inspection of the system. The seller is not required to provide information related to the soil on which the onsite system is sited, nor comment on the appropriateness of the onsite system with regard to the soil quality. The authors recommend incorporating such information in the residential disclosure form during the ongoing revision of the regulations concerning onsite wastewater treatment.

Table 4. Age of the property, categorized by the type of soil.

	Age of the property (years)	
Soil suitability	Median	Standard deviation
Leach fields	31	14.6
Mound systems	27	25.2
Onsite treatment with irrigation	18	28.5
Not suited for onsite systems	10.5	19.4

Apart from soil quality, other factors that result in the failure of septic systems include under-design, age of the system (DeWalle 1981, Mancl and Slater 2000), and failure to remove excess sludge from the septic tank (Mancl and Slater 2000). Unlike soil quality, these factors are within control once a property has been purchased. Adequate design and periodic removal of sludge can significantly enhance the performance of the septic system and prolong its operational life. The existing Ohio sewage rules do not mandate the periodic inspection of septic systems, and the authors are not aware of any attempt to include such a clause in the proposed new rules. In this regard, recent developments from Florida might be instructive where a law requiring mandatory inspection of septic systems every five years was annulled due to heavy public opposition (Jackson County Floridan 2010). While legislations on the management of septic systems may not receive immediate public support since the benefits from such increased regulations are not obvious, the authors believe that market-based incentives such as the one proposed in this study are more likely to gain support from residents and property owners.

10. Conclusions

The prohibitive cost of installing sewer networks in the exurban and rural areas of the country makes soil-based septic systems a suitable option, if installed and maintained properly. However, lack of information to the residents and the absence of strict policy guidelines governing this issue seem to be areas of concern. Based on the study conducted in Licking County, Ohio, quality of soil used for wastewater treatment has a positive impact on the price of the property. Properties sited on soils suitable for leach fields and mound systems are valued $14,062 and $12,897 higher than properties sited on soils suitable for onsite systems with irrigation or those unsuitable for any onsite systems, resulting in premiums of 6.8% and 6.2%, respectively. These price differences are more than the cost of installing a drip irrigation system and a mound system, respectively, thereby, creating an incentive for property owners to install advanced treatment systems on shallow soils. Federal- and state-assisted programmes could be used to provide relief for low-income homeowners who cannot afford to install the advanced treatment systems. Town boards and housing development authorities could give preference to developing plots that are well suited for onsite systems, and stipulate the creation of responsible management entities (RMEs) in plots with sub-optimal soils. For their part, property owners could hire certified soil scientists to identify the soil on which the onsite system is sited before purchasing a property. Better wastewater treatment improves ground and surface water, which in turn could lead to additional benefits such as improved health in the household and increased recreation in the area. Additional research needs to be conducted to capture the full economic impact of septic system siting and performance. It is hoped that a better understanding of the impacts of untreated wastewater would lead to better private and public policy decisions.

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