Modifications and Implications of Pricing Models: A Study of Assessed Property Values in Durham County, North Carolina

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Abstract

Determinants of property values have long been a central concern of urban economics. This paper explores the potential utility of using stochastic frontier functions, which assume the existence of a second, one-sided error term generated by inefficiency, to explain differentials in assessed property values. The reported empirical analyses employ both frontier functions and ordinary least-squares regressions to estimate the effects of standard property and community characteristics, such as acreage and distance from the city center, on property valuations. Additionally, the paper investigates the relationship between property values and land-use regulations, a relatively understudied factor in the shaping of local property markets. Data from Durham County, N.C., suggest that frontier functions are not particularly suited to analyzing well-publicized property valuations, implying that systematic inefficiency contributes little to these figures. Nevertheless, the results reaffirm the importance of incorporating zoning designations, which have highly statistically and economically significant effects on home values, into future research on property prices.

I. Introduction

Property prices are huge in both nominal terms and the effects they have on the economy.[*] In the United States, housing expenditures consume a significant proportion of consumers' budgets, and property values almost exclusively determine the tax receipts of many local governments. Property prices dictate the location decisions of households and businesses, the input ratios that producers select, and cities' geographic contours. Unsurprisingly, developing models that explain variations in property pricing has long been a central concern in the field of urban economics.

Modern urban economic theory interprets cities as complex entities, shaped by myriad observed and unobserved factors, from demographic changes to the presence and maintenance of local amenities. However, the fundamental reason for variation in the market price of land is simple and intuitive. Some locations are more desirable than others, and buyers will pay more for property in better locations. Property users derive benefit not only from the specific characteristics of an individual house, apartment, field, or office, but also from access to commercial centers, neighborhood attractiveness, and favorable regulatory policies.

To capture the effects of these varied determinants, researchers have adopted increasingly sophisticated methods of investigation, often conducting regression analyses that incorporate hedonic techniques to distinguish among the influences of diverse factors. Scholars, however, have published relatively little on the possibilities of using different types of regression analysis to better explain variations in property prices. Ordinary least-squares regressions remain the norm, even though work in other areas of economics suggests a variety of possible alternative approaches.

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[*] I am very much indebted to Charles Becker, research professor of economics, who suggested the topic and assisted me in preparing this paper for his course on Urban Economics. His guidance and thoughtful responses to my questions, both in and out of the classroom, were invaluable to my research. I wrote the paper as a senior at Duke University, from which I expect to graduate in May 2007 with a bachelor of arts in Medieval and Renaissance Studies and Economics. After my June wedding to another Duke alum, I shall begin working as an Associate at the Los Angeles office of The Boston Consulting Group. Please address any questions or comments, which I welcome, to meg.bourdillon@duke.edu.

Based on a study of assessed property values in Durham County, North Carolina, this paper investigates the potential of using stochastic frontier functions to explain price differences as a function both of standard explanatory variables and of semi-predictable, one-sided inefficiencies, with particular emphasis on the possible effects of often-understudied land use regulations. An empirical analysis of the data follows a more thorough discussion of the theoretical background and data sources. The conclusion then emphasizes implications for further research and, eventually, policymaking. Although the results indicate that frontier functions have little promise as a tool for investigating and explaining property prices in areas—such as Durham County—where the assessment process is transparent, the paper nevertheless highlights intriguing and important areas for future study.

II. Background

Because so many factors influence how much buyers are willing to pay to rent or own a specific piece of property, a rigorous analytical approach must somehow capture the effects of all these determinants. This paper takes as its starting point the now-standard approach of using hedonics to disaggregate the marginal changes in price that result from changes in each of several explanatory variables. As Kain and Quigley (1970) explain in their classic paper, "Measuring the Value of Housing Quality," households purchase a complex variety of services when selecting a home. Thus, only complex and rigorous hedonic analysis can permit estimation of "quantitative value estimates" or "implicit prices" for each element of the bundle of services a given property provides. More recent authors have continued to develop the hedonic approach first explored in the late 1960s and early 1970s, treating a wider variety of property types and incorporating more neighborhood amenities.

Scholars have developed several widely shared methods of incorporating the factors widely accepted as affecting property prices into OLS regressions. Wherever possible, specific property characteristics such as square footage, acreage, construction quality, and age appear in the model as explanatory variables. To reflect buyers' desire for proximity to commercial centers, most models incorporate a rent gradient, with the cost of property services dropping as distance from the center increases. Including statistics such as school performance, crime rates, and racial composition in the regression helps to account for households' neighborhood preferences.

Regrettably, researchers sometimes ignore the impact of governmental policies, but dummy variables are one way to represent their vital contributions to price differentials. Some authors (e.g., Sivitanidou 1995) have moved beyond partial models to explore general equilibria, addressing the interrelationships among business costs, neighborhood amenities, and wages demanded at a given location. Nevertheless, studies of property prices usually focus on either commercial or residential properties, largely because of the challenges inherent in compiling and analyzing evidence on such a variety of influences.

Still, even though the breadth of data required to conduct a thorough analysis is daunting, one potential information source both provides the evidence on which this paper's analysis relies and facilitates a nontraditional approach to thinking about property pricing structures. Many studies draw data from recent sales or subjective assessments of market value, generally compiled by local real estate agents, but these data often exhibit selection bias and can be difficult or costly to obtain. Property tax assessments, on the other hand, are publicly available for all properties, a quality that both facilitates research and eliminates the possibility that recent sold properties differ systematically from properties that have not recently changed owners. Assessments are characteristically stable and easily, spatially defined, making them a useful basis for both local governmental revenue (Smith 2000) and scholarly analysis.

Tax assessments differ significantly from market prices, though, in that interested parties have incentives to contest only one direction of potential error. The self-interested interactions of buyers and sellers of property will drive market prices of property ever closer to an expected or true value, with any errors that persist distributed normally above and below the expected price. In the case of tax assessments, however, only the businesses and households who own commercial and residential property face economic incentives to contest incorrect values. Moreover, they have reason to contest only overvaluations, which raise their tax burden. Because of agency problems and probable overwork, government officials have significantly less motivation to contest or readjust property valuations that work in taxpayers' favor. Logically, the error terms of tax assessments would therefore incorporate a one-sided component.

Literature on property tax assessments and the efficiency of valuation methods does not generally emphasize the possibility of one-sided error, but this is in part because of the policy-oriented concerns driving most research into tax assessment. Research into property taxes generally emphasizes the welfare implications and incidence of the tax payments, with a particular focus on the relative neutrality of taxes on land and developed property (Mandell 2001). Studies of error are related to but distinct from this policy-oriented body of scholarship. Gastwirth (1982) published the mathematical foundations that underlie the standard measure of assessment inaccuracy, termed the coefficient of dispersion, which is based on differences between assessed values and the median assessed value. He notes that in most places, the median ratio between assessed property value and actual market value is less than one, implying that tax assessments are more likely than not to benefit the taxpayer at the expense of government revenues. Still, even though Gastwirth does insist that a calculation robust to arbitrary distributions of error is necessary, his coefficient of dispersion does not require or even presuppose unidirectional error. Other tax researchers who consider assessment error focus on the progressive or regressive distributional implications of inaccuracy, as well as the expenses generated by the assessment system itself (e.g., Mehta and Giertz 1996). Clearly, the authors' aim is to foster equitable policies and enable the government more accurately to measure property prices, not to understand better the fundamental determinants of those values. The models these papers develop and employ reflect these policy-oriented concerns.

Interestingly, though, the literature seems not to exclude the possibility that the values generated through tax assessments exhibit some degree of one-sided error. If this is, in fact, the case, then a hedonic analysis of property prices using standard OLS methodology will incorrectly estimate standard deviations and coefficients. Rather, the image of an envelope or frontier better conveys the relationship between assessed values and the characteristics that determine them. A very small percentage of assessed property values will fall on or extremely close to an upper bound determined by actual market value, while the rest of the assessments will fall somewhere below this frontier.

Stochastic frontier analysis is an approach to regression that enables investigation of phenomena exhibiting this distinctive form and one-sided error. These procedures grew out of developments in modeling and understanding production technology. Proponents of frontier analysis argue that the production possibility frontier, a concept introduced to many students even in their first course in economics, can make using ordinary, two-sided error terms problematic. Rather, in an industry characterized by production at or below an efficient frontier, the distribution of firms' outputs is a function both of inputs and of a two-part error term, which includes "a new one-sided inefficiency component," as well as the more ordinary effects of random noise (Kumbhakar and Lovell 2000). Some tax assessment literature reveals an awareness of the difficulties inherent in handling error terms produced by deviation from a frontier, but Mehta and Giertz (1996) rely on a much simpler method, called corrected ordinary least squares, to investigate the cost efficiency of assessment calculation methods. This method incorporates only one-sided error, though, not the two separate error components posited in frontier models. The difference makes frontier analysis uniquely suitable for analyzing the possible implications of one-sided error for the study of actual property values, on which this paper centers.

In the regressions presented below, I test whether stochastic frontier analysis may actually be a useful and informative tool in examining the drivers of variation in property values. As outlined above, the probable presence of one-sided error in the tax assessment process might mean that frontier-based procedures will offer a more accurate indication of the coefficients and statistical significance of explanatory variables, since only the upper frontier of assessed prices will be at the market level. Furthermore, frontier analysis offers an important avenue for addressing the somewhat-understudied issue of governmental land use regulation, as manifested in zoning laws. Many economists argue that zoning imposes major inefficiencies and costs on the economy (e.g., Cheshire and Sheppard 2002), and if zoning functions to create a one-sided inefficiency in property pricing, then frontier analysis could be an important tool for better understanding the distributive and welfare implications of governmental land regulation.

Therefore, I use as my basic model the general equation for a stochastic production frontier presented by Kumbhakar and Lovell (2000),

$$\ln y_i = \ln f(x_i, \beta) + v_i - u_i \, . \qquad (1)$$

In this model, β represents the coefficients to be estimated, and x_i represents the explanatory variables included in each regression. The dependent variable appears as y_i,. and the two error terms are v_i and u_i. The former is an ordinary, normally distributed error term, which captures errors in data collection and the effects of any randomly distributed, unobserved variables on actual property values. The latter is a one-sided measure of technical inefficiency, which should reflect both uncontested undervaluation and the effects of any other determinants that increase the likelihood that a property will not be assessed at its market value. Kumbhakar and Lovell outline techniques for incorporating exogenous influences on this latter error term. They break down u_i into systematic and random components, summarized as

$$u_i = \lambda' z_i + \varepsilon_I , \qquad (2)$$

where z_i represents the exogenous influences on u_i, and λ' represents the coefficients on those variables. ε_i is the remaining random component of the technical inefficiency. This technique permits research into variables that may explain the inefficiencies in y_i, thereby helping this study to explore the possible role of zoning codes as a source of variation in u_i.

The reported frontier analyses below rely primarily on equation (1) and present the values and standard errors of β that STATA calculated using maximum likelihood estimation. The OLS regressions also presented use standard log-log forms. Although a broader collection of data and a more general approach is ultimately preferable, because this paper's purpose is to offer a preliminary exploration of possible avenues and techniques for further research, this study focuses on the most essential elements of hedonic analysis: major property characteristics, location, and rudimentary proxies for neighborhood quality. These comprise the variables represented in (1) by x_i and permit this paper's examination of potential modifications to standard approaches to modeling variation in Durham's property prices.

III. Data

The evidence on which this paper draws to investigate these relationships and the effectiveness of frontier analysis comes from a variety of public sources, somewhat facilitating the research process. This work draws from both research-oriented governmental websites and sites designed for consumers, linking this paper to the information buyers actually use to make their property purchasing decisions. Unfortunately, the limitations of these sources and on time available to compile data were major barriers to identifying statistically significant relationships theory would predict.

Data on assessed property value, the dependent variable around which this study revolves, are drawn from the public records provided by the Durham County Tax Administrator's Office. To fairly reflect changes in valuation, these assessments are revised every eight years—most recently in 2001—and a major component of the tax administrator's job is to determine property tax valuations that reflect the market value in the last reassessment year (Durham County Government). These records are most easily accessible through the Geographic Information Systems interface (Durham GIS), which makes regularly updated governmental statistics and records available online to researchers and the public. The dataset used in the analysis presented here contains observations on 150 tax parcels randomly selected from all parcels in Durham County, N.C. The graphs in Appendix 2 offer a visual overview of the tax parcels observed and their size in acres. As the figures demonstrate, residential observations dominate the sample, and parcels not in residential use often appear to have outlying values. For each parcel, the GIS website provided the location, total acreage, zone code, land use classifications, and census tract, as well as the assessed land, building, and total values.

The street address furnished by the GIS system permits the calculation of distance from the city center, traditionally thought to determine the property's position on a rent gradient and, hence, its price. Choosing as the city's "center" an address in the middle of a downtown area that includes both governmental offices and several urban redevelopment projects, I estimated the driving distance between each tax parcel and downtown. This measure better reflects the actual accessibility constraints of a given location than would a straight line and is also easier to calculate, due to the proliferation of services offering street maps and directions. In this case, I used Mapquest to determine the route that is the "shortest distance" by road between each address and downtown, using the address of a nearby intersection whenever an undeveloped property was not yet in Mapquest's files. The result is a nontraditional but consistent and relevant measure of distance from the city center.

Two additional sources of real estate data, Zillow and RealEstateABC, draw from similar pools of detailed information on individual residential properties. From them, I compiled information on year built, number of bedrooms, and square footage, whenever figures were available for a given house. The main problem with these sites is the scattered nature of the available data. Few houses not sold in the past five to ten years appear on the sites, generating possible selection bias. Even more significantly for this study, since only 50 percent of my original observations were residential properties for which I could obtain information on square footage, using this variable drastically decreased the size of the sample on which many of the regressions presented below rely.

Finally, to obtain proxies for neighborhood quality and amenities, this paper draws from the statistics on the census tract in which each property lies. In particular, the percentage of households living in owner-occupied housing in 2000 and the median household income in 1999 both figure into the analyses below (U.S. Census Bureau). These measures of neighborhood quality are far from ideal, because they clearly have a causational effect on property prices in the area, since a higher-income household has more income to spend on property services. Nevertheless, the absence of crime statistics broken down by census tract necessitated the use of these figures as proxies. Although one researcher has used overlaid mapping techniques to identify the murder rate per 100,000 residents in each of the Durham County census tracts (Abram 2005), incorporating the midpoints of his ranges as an explanatory variable revealed no statistically significant effects on assessed property values. Clearly, analysis of crime's relationship to property values demands a broader and more detailed dataset. Thus, although the variables used here to account for location-based amenities are highly imperfect, they offer the best available proxies for neighborhood quality, given constraints on the author's skill, time, and resources. In this case, as with the other sources of data for this paper, the imperfections are insufficient to prevent an exploration of the determinants of property values in Durham and whether frontier analysis could be a useful tool for further research.

IV. Analysis and Discussion

A. Definitions of Variables

The subjects of this paper's analysis fall into three broad categories: determinants of land value, denoted L_i; determinants of total property value, denoted T_i; and the relative efficacy of frontier and OLS regressions in examining these determinants. Therefore, the regressions in this paper use natural logs of all linear variables, unless otherwise specified; the log-log functional form permits easier comparison between OLS results and the frontier regressions, which generally demand log transformations of all variables to produce meaningful results. A_i, S_i, and Y_i—which represent acreage, square footage, and building age—account for the specific characteristics of each property. Distance from downtown, D_i, controls for the existence of a rent gradient. Proxies for neighborhood quality are census tract-wide estimates of the murder rate per 100,000, M_i; the median household income, I_i; and the percentage of households who own their own homes, O_i. Finally, including the quadratic terms D^2_i, A^2_i, and A^3_i allows for the possibility that increases in distance from the center and acreage have non-linear effects on property prices.

Dummy variables used to explore the effects of governmental regulations also appear in several of the regressions. RR_i equals 1 if the property's zoning code is one of several indicating "Residential Rural Density" zoning; otherwise, RR_i equals 0. Similarly, a value of 1 for RL_i, RM_i, or RH_i respectively indicates "Low Density," "Medium Density," or "High Density" residential zoning. A value of 1 for RS_i reflects any sort of residential zoning; notably, only 10 properties in the sample were not zoned for residential use. The interaction term DR_i is a measure of distance from downtown that equals zero unless the property in question is zoned for rural-density residences. Additionally, one regression corrects for the fixed neighborhood effects represented by census tract designation, a technique that relies on a dangerously small number of observations within each tract but nevertheless offers a potentially useful way of capturing omitted variable bias. The estimated coefficients for these and various other specifications appear in tables in Appendix I.

B. Simple Models, Surprising Results

Despite the simplicity of the OLS models presented in the first few tables, they have important implications for understanding and analyzing this set of data. Table 1 reports on an extremely simplistic regression, examining (linear) land value as a straightforward function of (linear) acreage. As theory and common sense would predict, land values are strongly positively and statistically significantly correlated with property size, but the relationship between land valuation and acreage is non-linear. The coefficients here show that, as acreage expands, assessed land value first increases steeply and then rises more slowly. This predictable result offers an early indication that the data used here reflect at least some of the usual trends on which location theory depends.

Several results of using the specifications in Models 2, 3, and 4, however, are somewhat unexpected and puzzling (Table 2). Many of the coefficients demonstrate the expected patterns, and the high R^2 values for all three regressions suggests that the Durham County property market generally demonstrate a predictable association between desirable housing services and house prices, but the results nevertheless suggest that the theories outlined in Section II do not fully apply to Durham. Model 2 is an analysis of total assessed property value as a function of four standard variables, A_i, S_i, Y_i, and D_i. Logically, the coefficients on A_i and S_i should be positive, while the coefficients on Y_i and D_i should be negative. Although the estimated coefficients on the first three variables have the expected signs and are reasonably statistically significant, the coefficient on D_i is actually positive. Indeed, this coefficient has the negative sign that theory would predict only in Model 4, when median household income is included as an explanatory variable. Even then, the coefficient on D_i is relatively statistically insignificant, compared to the coefficients on the other regressors.

This relative lack of homeowner preference for proximity to the town center may be initially surprising to those more familiar with cities that have monocentric structures. Durham is a city of very low density, and its downtown experienced a major economic downturn during the second half of the twentieth century, which may explain the apparent lack of association between property location and price. Many commuters may choose their home location for its proximity to a network of freeways or to Duke University, so the city could have many smaller commercial nodes rather than one dominant center. Even though using M_i as an explanatory variable did not give D_i the predicted negative sign, this variable's statistical insignificance suggests that it does not accurately capture the effects of local crime rates on Durham County, and the perceived high crime rate in central parts of Durham may still be a major factor leading homebuyers to flee from the city. Whatever the reason, wealthy residents' tendencies to avoid downtown Durham are sufficiently strong to mostly outweigh the centralizing forces reflected by a standard rent gradient, and they keep property prices from increasing steeply as distance from the downtown area decreases.

Even more unexpectedly, all of these initial models also indicate very strongly that stochastic frontier analysis is unsuited to study of property prices. Frontier regressions based on these models consistently estimate that the one-sided component of error is non-existent and that the p-value for rejecting the null hypothesis is 1.000. Table 3 shows the results of using frontier regression on natural-log transformations of the variables in Models 2 and 4.[1] Interestingly, they generate coefficients almost identical to those estimated using OLS regression, providing further evidence that stochastic frontier analysis brings no new insight to these simple studies of property valuation.

The lack of a one-sided error term in tax assessment could stem from several factors, but one possibility is that the regular reassessments in North Carolina, as well as the mathematical nature of the calculations used by the tax assessment office, minimize all potential deviation from the true market value. If deviations are small, the transaction costs of challenging an overvaluation would exceed the expected returns of legal action, so both undervaluations and overvaluations could persist unopposed. Another possibility is that the size of this dataset is insufficient, but these regressions' extremely high p-values and complete failure to reject the null hypothesis suggests that no amount of data could make this approach to regression analysis effective. The equation specified in (1), apparently, does not help to explain variation in Durham County property prices.

C. Governmental Regulation: Zoning and Distance

The relative success of Model 4, where the inclusion of median income as an explanatory variable raises the R^2 value and shifts the sign on D_i's coefficient to match the theoretical prediction, makes the model the best starting point for deeper analyses incorporating governmental regulation. Moreover, since neither the murder rate nor the owner occupancy rate proved useful or statistically significant, including I_i is the best way to correct for neighborhood quality within this dataset. Table 4 presents several models, each a variation on Model 4 that also incorporates a term corresponding to a form of residential zoning.

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[1] Because so many census tracts had no murders in 2004, a natural-log transformation of the murder rate is neither useful nor relevant.

Although the coefficient on RL_i is not significant at any standard level—possibly because of the scarcity of observations—the sign is positive, as one would expect for a zoning classification intended to preserve the grassy lawns, well-spaced homes, and high property values of suburbia. OLS regressions incorporating RM_i and RS_i showed less significance, though; neither of these hypothesized explanatory variables appears in the reported regressions. By far the most significant estimate is the coefficient on RR_i, which designates property zoned for rural residences. The negative sign reflects this zoning designation's restrictive effects on the owner's option value, since he cannot greatly develop his land or sell it to a developer without significant legislative or lobbying effort. This regression predicts that, all other factors being equal, a rural residential zoning designation decreases a property's total assessed value by approximately 28 percent, a highly economically significant amount.

A similar level of economic and statistical significance appears in Table 5, which reports the results of frontier regressions using modified forms of Model 5 and Model 7.[2] Here, the rural- or high-density zoning categories enter into the regression as determinants of the one-sided inefficiency term, following the model outlined by Kumbhakar and Lovell in (2). Notably, though, the p-value on the error term's constant element is still .999 or 1.000, providing further confirmation that this functional form is not the best way to model variation in property prices.

Other OLS regressions show more promise, though a few attempts to produce analogous estimates for zoning dummies' effects on land value produced results that were relatively statistically insignificant. When using a fixed-effects regression to test whether zoning designations continue to be influential within each census tract, a restriction that holds constant myriad unobserved neighborhood effects, rural-density residential zoning came closest to meeting a standard level of statistical significance, but the p-value on its coefficient was still a high .289 (Table 6). Nevertheless, given the relatively limited number of observations (75) in this sample and the large number of census tracts (31), this result suggests that analysis using a larger dataset could easily show that rural-density zoning remains statistically significant.

[2] Frontier regressions including both zoning categories and median income produced nonsensical results, so I excluded I_i from these regressions.

Overall, the alternative specifications seem to indicate a persistent level of economic and statistical significance for rural-density zoning.

Interestingly, the incorporation of RR_i into these models seems generally to decrease the p-value for the coefficient on D_i, suggesting a strong relationship between the two variables. This could indicate that the apparent significance of RR_i as an explanatory variable is merely a result of endogeneity, since distant, less valuable homes are almost certainly more likely to be zoned for rural residential use. To test this possibility, I added the interaction term DR_i to Model 5, producing the results that appear in Table 7. The statistical significance of both DR_i and RR_i disappears in Model 9, although an F-test of the two variables produces a p-value of .0193, using robust standard errors, indicating that the two factors still jointly have a significant impact on the model and the assessed property value. Model 10 bears out this trend, with the coefficient on DR_i once again becoming statistically significant, following the exclusion of RR_i from the regression. These results tentatively show that, despite the role that distance from an urban center plays in reducing the value of homes zoned for rural residential usage, tax parcels given the "Residential Rural Density" designation receive even lower property valuations than other comparable, similarly located properties. Overall, these results hint at the economic importance of zoning and governmental land-use regulations, although the data presented here are not sufficiently detailed or extensive to identify thoroughly the extent of zoning's impact.

V. Conclusion

Despite limitations this paper's limited breadth and depth, the study presented here nevertheless reveals or confirms many important characteristics of property valuation. Indeed, despite the study's focus on a single county with an unusual demographic composition situated in an atypical region full of fast-growing, nearly merging urban areas, the paper's results conform to most of the basic predictions of urban economic theory. The analysis presented here both substantiates the accuracy of current theory and reaffirms the value of continued research in the field.

Assessed valuations in Durham clearly demonstrate the relationships theory indicates with the basic property characteristics that typically make a house or commercial building more or less desirable: age, square footage, and acreage. On the other hand, the negative relationship of property value with distance from the area's center is somewhat weaker than usual and takes on a positive sign when the neighborhood's median income does not appear in the regression, which suggests that flight of the wealthy to city suburbs and other motivations for less dense settlement have affected the development of Durham County in significant ways. Nevertheless, the rent gradient's relative weakness cannot undermine the fact that, even in this relatively small sample, the basic predictions of hedonic pricing models hold true. Coefficients on the most economically significant factor, square footage, indicate that a doubling of the area within a house is associated with an approximately 75-percent increase in property value. The implicit prices that homeowners pay for square footage, acreage, and newness are high.

Additionally, even the preliminary estimations conducted using such a small sample hint at the economic significance of certain land use policies. The results here reveal that rural-density residential zoning has a strongly economically and statistically significant effect on property valuation, and they hint that low- and high-density rural zoning classifications may also have an important impact on property values. The lack of statistical significance for some of these coefficients in many specifications could easily be a function of the restricted sample size used in this paper, which suggests that further research could help Durham County policymakers to better understand the welfare implications of their zoning decisions.

This research, however, should be conducted using OLS and not frontier regressions. Although the methods of constructing and contesting tax assessments suggest the possibility that they could include a one-sided error term, this appears not to be the case. Indeed, the results of the analyses presented here reject that possibility strongly enough perhaps to deter further investigation of the procedure's relevance, although the method might be more suited to analyzing data from counties with less transparent assessment procedures or higher degrees of corruption. The results presented in this paper attest to the hard and effective work of Durham County's tax assessors and also, probably, to the high transaction costs involved in appealing an overvaluation of real estate. Moreover, that the effects of zoning or other, unobserved determinants on property valuation cannot be modeled as "technical inefficiency" has interesting intellectual implications for understanding and studying property prices and the consequences of zoning. Rather than increasing the likelihood that an assessor will undervalue a property, zoning designations can actually alter the property's true value. Thus, this study reveals both the relative effectiveness of standard functional forms and the importance of including governmental regulations in future research into property valuation.

Appendix I: Tables

Table 1. Effects of Acreage on Land Value

	Model 1	
Variable	OLS Coefficient	P-value
A_i	59811.57	0.000
A^2_i	-2132.74	0.000
A^3_i	12.02	0.000
Cons.	6612.20	0.592
No. Obs.	150	
R^2	0.3236	
Adj. R^2	0.3097	

Table 2. Effects of Property and Neighborhood Characteristics on Total Value

	Model 2			Model 3			Model 4		
Variable	OLS Coefficient	P-value	Robust P-value	OLS Coefficient	P-value	Robust P-value	OLS Coefficient	P-value	Robust P-value
A_i	0.1200124	0.055	0.099	0.1102444	0.081	0.128	0.1656653	0.003	0.023
S_i	0.7582738	0.000	0.000	0.761856	0.000	0.000	0.69015	0.000	0.000
Y_i	-0.1740355	0.000	0.002	-0.1639522	0.001	0.003	-0.1601932	0.000	0.001
D_i	0.189652	0.016	0.032	0.1828049	0.021	0.045	-0.190396	0.072	0.120
M_i				-0.0022059	0.322	0.354			
I_i							0.6632992	0.000	0.000
Cons.	6.656131	0.000	0.000	6.61033	0.000	0.000	0.5947573	0.697	0.703
No. Obs.	75			75			75		
R^2	0.6828			0.6855			0.7613		
Adj. R^2	0.6647			0.6627			0.7440		

Table 3. Effects of Property and Neighborhood Characteristics (ln) on Total Value Estimated Using Frontier Regression

Variable	**Model 2** OLS Coefficient	P-value	**Model 4** OLS Coefficient	P-value
A_i	0.1200124	0.043	0.1656653	0.002
S_i	0.7582739	0.000	0.6901501	0.000
Y_i	-0.1740355	0.000	-0.1601932	0.000
D_i	0.189652	0.011	-0.190396	0.057
I_i			0.6632993	0.000
Cons.	6.658157	0.000	0.5960216	0.691
No. Obs.	75			
Log likelihood	-11.6281		-0.9743	
Test of sigma_u=0	0.00	1.000	0.00	1.000

Table 4. Effects of Zoning on Total Value, OLS Regressions

Variable	**Model 5** OLS Coefficient	P-value	Robust P-value	**Model 6** OLS Coefficient	P-value	Robust P-value	**Model 7** OLS Coefficient	P-value	Robust P-value
A_i	0.2211784	0.000	0.002	0.1575011	0.005	0.041	0.1539699	0.006	0.040
S_i	0.7118075	0.000	0.000	0.7081449	0.000	0.000	0.6882444	0.000	0.000
Y_i	-0.1474739	0.000	0.004	-0.1478683	0.001	0.004	-0.1587526	0.000	0.002
D_i	-0.1357102	0.191	0.298	-0.1938499	0.065	0.112	-0.2089925	0.049	0.087
I_i	0.6365629	0.000	0.000	0.616468	0.000	0.000	0.6430975	0.000	0.000
RR_i	-0.2831939	0.014	0.006						
RL_i				0.0701154	0.155	0.150			
RH_i							-0.1790009	0.148	0.060
Cons.	0.7084139	0.630	0.636	0.8759511	0.567	0.563	0.8481602	0.578	0.561
No. Obs.	75			75			75		
R^2	0.7816			0.7683			0.7686		
Adj. R^2	0.7623			0.7479			0.7481		

Table 5. Effects of Zoning on Total Value, Frontier Regressions

	Variable	**Model 5b** OLS Coefficient	**Model 5b** P-value	**Model 7b** OLS Coefficient	**Model 7b** P-value
	A_i	0.1858891	0.003	0.1064651	0.070
	S_i	0.7799959	0.000	0.753041	0.000
	Y_i	-0.1587851	0.000	-0.1715874	0.000
	D_i	0.2348691	0.001	0.1499875	0.049
	Cons.	6.516165	0.589	6.833345	0.984
mu	RR_i	0.325913	0.008		
mu	RH_i			0.2353211	0.077
mu	*Cons.*	0.0101075	0.999	0.086774	1.000
	No. Obs.	75		75	
	Log likelihood	-8.2999		-10.0929	

Table 6. Effects of Rural Residential Zoning on Total Value, Accounting for Census Tract

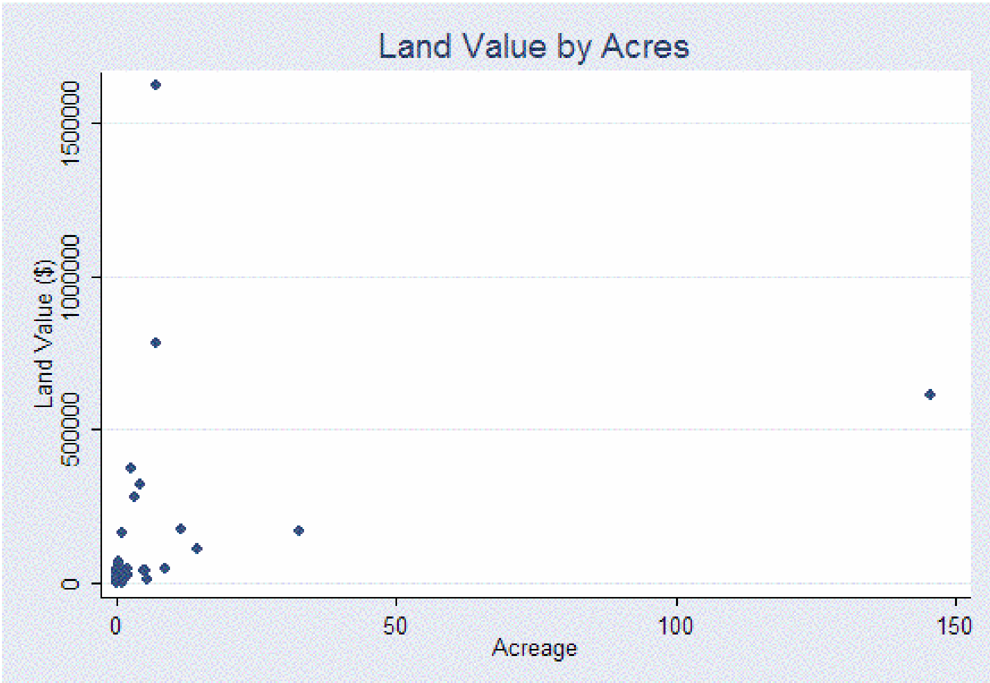
Variable	**Model 8** OLS Coefficient	P-value	Robust P-value
A_i	0.2538152	0.001	0.019
S_i	0.5770627	0.000	0.000
Y_i	-0.1428105	0.004	0.032
D_i	0.6027813	0.033	0.027
RR_i	-0.1418957	0.289	0.355
Cons.	7.43451	0.000	0.000
Tract		0.002	
No. Obs.	75		
R^2	0.9056		
Adj. R^2	0.8209		

Table 7. Effects of Rural Residential Zoning on Total Value, Incorporating Distance Interaction

Variable	**Model 9** OLS Coefficient	P-value	Robust P-value	**Model 10** OLS Coefficient	P-value	Robust P-value
A_i	0.2121332	0.001	0.003	0.2177286	0.000	0.003
S_i	0.7120217	0.000	0.000	0.7121395	0.000	0.000
Y_i	-0.1430974	0.001	0.005	-0.1453734	0.000	0.004
D_i	-0.1278835	0.225	0.336	-0.1316058	0.205	0.316
I_i	0.6378848	0.000	0.000	0.6368642	0.000	0.000
RR_i	0.3554307	0.771	0.729			
DR_i	-0.3091288	0.600	0.532	-0.1385749	0.013	0.005
Cons.	0.6553741	0.659	0.662	0.685876	0.641	0.646
No. Obs.	75			75		
R^2	0.7825			0.7822		
Adj. R^2	0.7597			0.7630		

Appendix 2: Figures

Figure 1. Acreage and Land Value of Observed Parcels



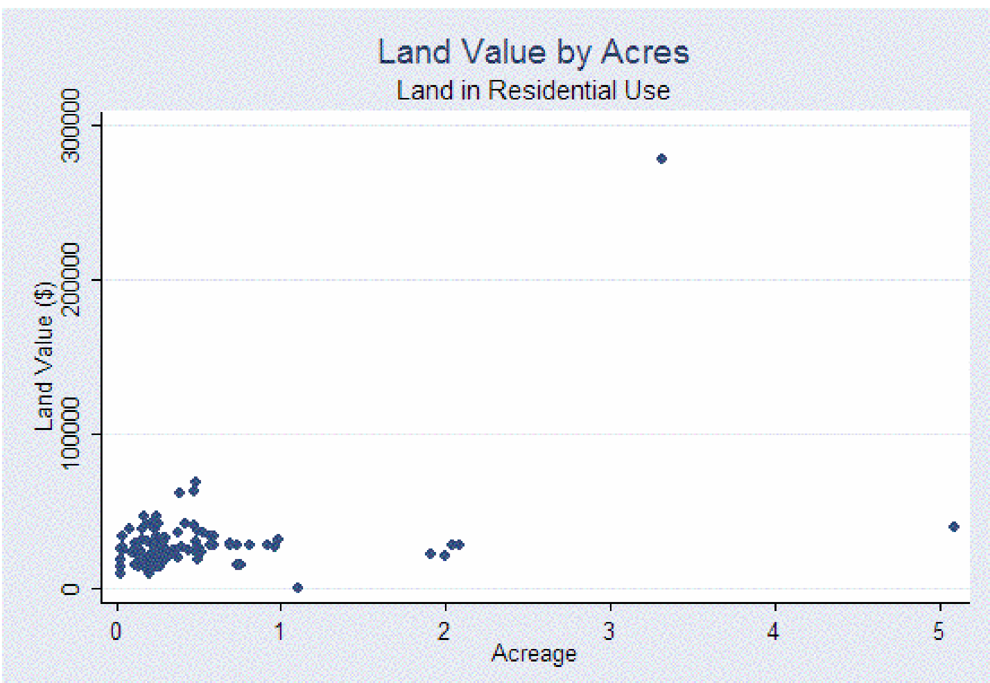
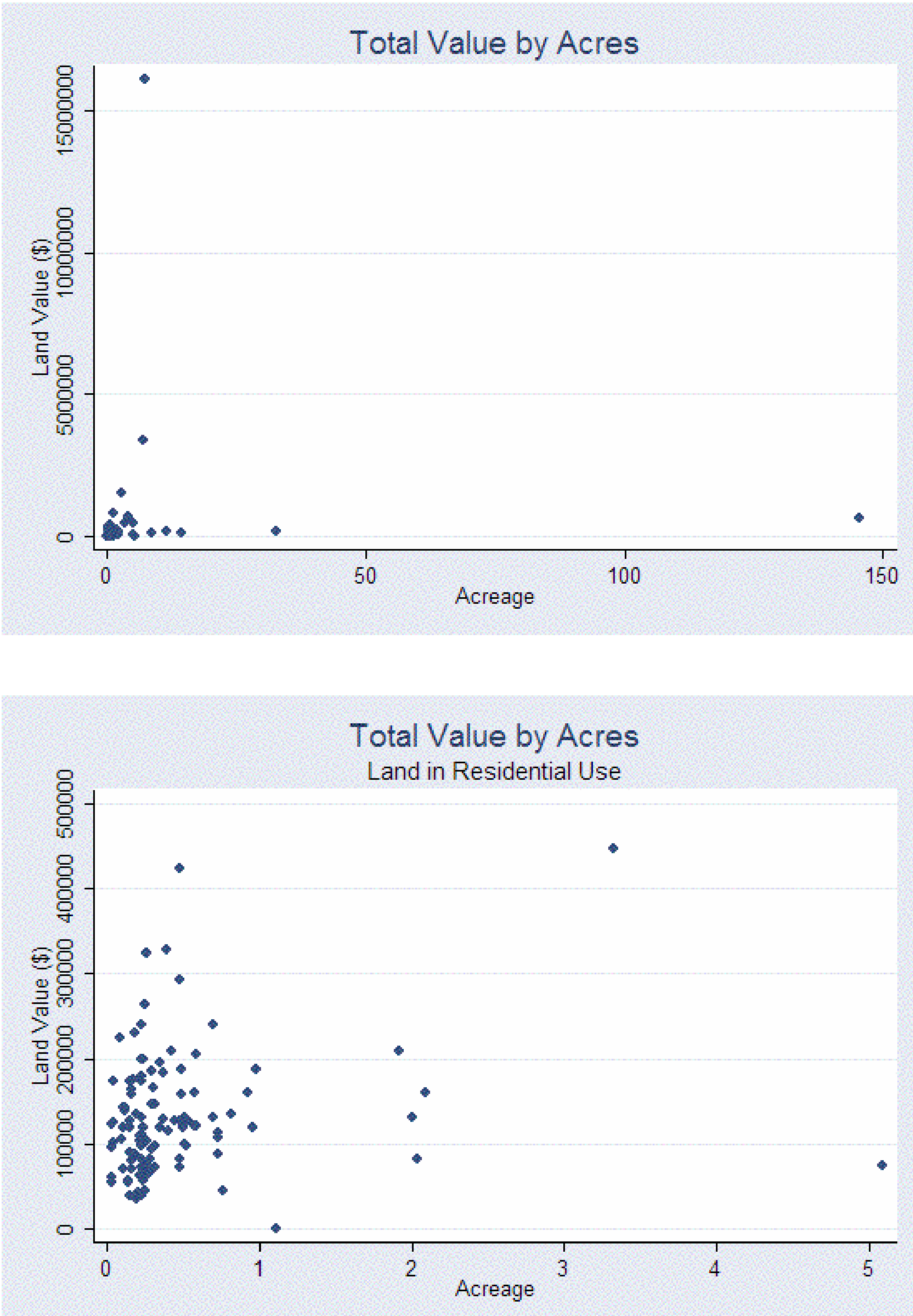


Figure 2. Acreage and Total Value of Observed Parcels



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