The Cost of Convenience: Estimating the Impact of Communication Antennas on Residential Property Values

Stephen L. Locke and Glenn C. Blomquist

ABSTRACT. *This paper applies hedonic and quasi-experimental methods to measure the disamenity value of communication antennas. We take advantage of a rich dataset of residential housing sales from central Kentucky that contains an extensive set of structural housing characteristics and precise location information. This allows us to overcome endogeneity issues caused by unobservable characteristics correlated with antenna location. The best estimate of the impact is that a property with a visible antenna located 1,000 feet away sells for 1.82% ($3,342) less than a similar property located 4,500 feet away. The aggregate impact is $10.0 million for properties located within 1,000 feet.* (JEL Q51, R21)

I. INTRODUCTION

Accompanying the desirable growth of cell phone and wireless Internet usage has been the not-so-desirable appearance of communication antennas. Cell phone usage worldwide, and especially in the United States, has grown fast. According to the Cellular Telephone Industries Association, in December of 1998 there were 69.2 million wireless subscribers. Fifteen years later, in December 2013, that number was 335.7 million.[1] To put this in perspective, the U.S. Census Bureau estimated the population to be 270.2 million in 1998 and 316.5 million in 2013. The United States has gone from 25.6% of the population having a wireless subscription in 1998 to more than one subscription per person in 2013. With the advances in mobile technology it is possible to do nearly every task that was once only possible on a desktop computer on a mobile device that fits in the palm of a hand. Like any other good or service, the added convenience of mobile technology has costs.

Economists have long been interested in estimating impacts of disamenities in urban areas. For examples see Mieszkowski and Saper (1978) on airport noise, Kohlhase (1991) on toxic waste sites, and Kiel and Williams (2007) on Superfund sites. An area that has received little attention is the disamenity associated with cell phone towers and communication antennas. As the demand for cell phones and mobile technology increases, it is followed by an increase in demand for reliable coverage, which in turn leads to an increase in the number of antennas. In the mid-1990s there was a sharp increase in the number of antenna structures to accompany the mobile phone technology that was becoming more prevalent. Choosing the location for an antenna involves conflicting incentives for residents. Land owners may want to have an antenna located on their property because it provides an additional source of income and better cell phone reception for residents in its vicinity.[2] However, these structures are visually unpleasant. Residents tend to object to having them located nearby because of the visual disamenity they create or because of adverse health effects they may associate with

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[1] Visit http://www.ctia.org/ for more information about the growth of cellular subscriptions in the United States.

[2] Airwave Management, LLC, provides some insight into the amount of income these cell phone towers can generate for a land owner. According to their website, payments can reach as high as $60,000 per year (www.cell-tower-leases.com/Cell-Tower-Lease-Rates.html).

Land Economics • February 2016 • 92 (1): 131–147
ISSN 0023-7639; E-ISSN 1543-8325

The authors are, respectively, assistant professor, Department of Economics, Western Kentucky University, Bowling Green; and professor, Department of Economics, Martin School of Public Policy and Administration, University of Kentucky, Lexington.

the antennas.[3] Towers are often highly visible, and potential siting can induce objections from residents in the receiving neighborhood. Municipalities have used delays in the approval process in an attempt to appease protestors and possibly prevent siting.[4] Unlike some disamenities such as airport noise, information about the visual disamenity is available.[5]

Figure 1 illustrates when an externality is likely to exist, and the situation when a nearby antenna could provide a net benefit to nearby residents. In the upper photo, an antenna is located on a property adjacent to a residential subdivision. Regardless of any compensation, the antenna structure is likely to be considered a disamenity by nearby residents.[6] The lower photo shows an antenna that could provide a net benefit to nearby residents. The structure located at point A is hidden behind a thicket of trees and far enough away from the nearest neighbor (point C) so as not to impose any cost. If the owner of the property at point B owns the land where the antenna is located, the owner is receiving payments from the antenna's owner, while nearby residents receive the benefit of improved coverage. In this situation the potential disamenity is mitigated by trees. Having an antenna located nearby should not decrease property values; it probably increases property values where the antennas are located.

The purpose of this paper is to apply hedonic and quasi-experimental methods to measure any disamenity caused by communication antennas, controlling for endogenous antenna location and changes in unobserved housing and neighborhood characteristics. Spatial fixed effects are used to control for any time-invariant unobservables correlated with proximity to an antenna. The repeat sales method and quasi-experimental techniques are used to address time-invariant and time-varying unobserved characteristics that could affect the equilibrium hedonic price function. Quasi-experimental techniques are becoming increasingly common in the environmental economics literature and are used instead of instrumental variables when there is not random assignment into treatment and control groups (Greenstone and Gayer 2009).

II. RECENT WORK ON VALUING AMENITIES/DISAMENITIES

Omitted variables are a concern when estimating hedonic price functions. Following Rosen (1974), the hedonic price function of property i can be represented by $P_i = P(S_i,N_i,Q_i)$, where P_i is the price of property i. S_i, N_i, and Q_i are the structural, neighborhood, and environmental characteristics, respectively. Consumers have utility $U = U(X,S_i,N_i,Q_i)$, which is maximized subject to the budget constraint $P_i + X = M$, where X is a Hicksian composite commodity with price equal to \$1, and M is income. This gives the following first-order condition:

$$\left(\frac{\partial U}{\partial Q_i}\right) \Big/ \left(\frac{\partial U}{\partial X}\right) = \frac{\partial P_i}{\partial Q}. \qquad [1]$$

The marginal rate of substitution between the environmental characteristic and the composite good X is equal to the slope of the hedonic price function (market clearing locus) in the environmental characteristic Q_i. Once the hedonic price function P_i has been estimated,

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[3] Despite concerns about negative health effects from the radio waves emitted from mobile devices, a comprehensive study of the health effects related to cell phone and cell phone antennas by Röösli et al. (2010) finds that there is no conclusive evidence that using cell phones or living near cell phone towers harms human health. Nevertheless, the perception of such risks may be sufficient to alter behavior.

[4] See City of Arlington, Texas *v.* Federal Communications Commission, 133 S. Ct. 1863.

[5] A recent article by Alcantara (2012), with AOL Real Estate, highlights the concerns residents have about having a communication antenna located near their property. As reported, a group of residents in Mesa, Arizona, is protesting the siting of a cell phone tower in the group's neighborhood. One resident is quoted as saying, "Apart from the tower being so tall, we all feel that property values will go down if they build it so close. Most people I know wouldn't want to buy a house near a cell phone tower."

[6] If the structure was constructed *before* the residents moved in or built a house in this subdivision, no uncompensated externality exists. They have preferences such that the structure does not affect them, or they were compensated for the visual aspect of the structure though a lower purchase price. However, if the structure was constructed *after* the residents moved in or built in this subdivision, they are affected by the sight of the structure and a lower sales price if they do decide to sell the property. The land owner where the structure is located is receiving payments from the antenna's owner, while all affected nearby residents are not being compensated.

FIGURE 1

Houses Likely Affected *(upper photo)* and Houses Likely Not Affected *(lower photo)* by Nearby Antenna

Source: Google Earth 2014, 2015.

the partial derivative of P_i with respect to the environmental characteristic Q_i is equal to the implicit price of the environmental characteristic. However, when there are characteristics unavoidably omitted from P_i that are correlated with Q_i, the estimate of willingness to pay for Q_i will be biased. Endogeneity in the location of the antenna structures is the greatest concern in estimation. Holding all else constant, owners of the antenna structures are going to locate them in areas where it costs the least. If not taken into account, this incentive will lead to an overestimate of the negative impact these structures have on property values. Other issues that have to be addressed in estimation concern buyers' sorting (Cameron and McConnaha 2006; Bayer, Keohane, and Timmins 2009; Bieri, Kuminoff, and Pope 2012; Kuminoff, Smith, and Timmins 2013) and the stability of the hedonic price function (Kuminoff and Pope 2014; Haninger, Ma, and Timmins 2014). To address the sorting concern, spatial fixed effects are included to control for unobservables that may influence both buyers' location choices and the location of communication antennas. The most recent panel data techniques that address both time-invariant and time-varying unobservables are used to account for the possibility of a changing hedonic price function after the construction of a nearby antenna.

While Rosen (1974) shows that the partial derivative of P_i with respect to Q_i provides an estimate of the willingness to pay for a small change in the environmental good Q_i, the appropriate functional form for the hedonic price function is uncertain. Cropper, Deck, and McConnell (1988) use simulations to determine how different functional forms perform when there are omitted variables in the hedonic price regression. They find that flexible functional forms perform well when all of the attributes are included, but recommend using a more parsimonious functional form when there are omitted variables. Since Cropper, Deck, and McConnell's (1988) work, sample sizes have increased dramatically, advances in geographical information systems allow researchers to control for previously unobserved spatial characteristics, unobserved structural housing characteristics are much less of a concern, and quasi-experimental techniques have become more prevalent. Kuminoff, Parmeter, and Pope (2010) find that Cropper, Deck, and McConnell's (1988) recommendations should be reconsidered. When using cross-section data, Kuminoff, Parmeter, and Pope (2010) find that the quadratic Box-Cox functional form with spatial fixed effects performs best. However, for practical purposes, including spatial fixed effects significantly reduces bias regardless of the functional form used.[7]

Kuminoff, Parmeter, and Pope (2010) also show that exploiting variation in an environmental amenity for properties that sell multiple times can reduce bias in willingness-to-pay estimates compared to pooled ordinary least squares with fixed effects. If the spatially correlated unobservables are time invariant, their effect will be purged from the model when first differences are taken. However, if the unobservables are not time invariant, the estimates from a repeat sales model will be biased. Repeat sales models have recently been used to estimate the impact of changing cancer risks (Gayer, Hamilton, and Viscusi 2002), the siting of wind farms (Heintzelman and Tuttle 2012), Superfund site remediation (Mastromonaco 2014), and reductions in three of the U.S. Environmental Protection Agency's criteria air pollutants (Bajari et al. 2012).

While there are advantages of using the repeat sales method and quasi-experimental techniques to eliminate the bias caused by time-invariant unobservables, these methods estimate a capitalization rate that is not necessarily equal to the marginal willingness to pay. It is possible that the presence of, or change in, an environmental (dis)amenity can cause the hedonic price function to change over time. Kuminoff and Pope (2014) and Haninger, Ma, and Timmins (2014) show that as long as the hedonic price function is constant over time, there should be no difference between the capitalization rate and the marginal willingness to pay. Given that the communication antennas are expected to have relatively small impacts on property values, it is unlikely that the construction of a new antenna structure will lead to a change in the hedonic price function. But, this issue will be addressed.

Kuminoff, Parmeter, and Pope (2010) find that a generalized difference-in-differences estimator with interactions between the time-dummy variables and housing characteristics to allow the shape of the price function to change over time performs best when panel data are available. Linden and Rockoff (2008) provide a technique for defining treatment and control groups so that difference-in-differences can be used to estimate the impact of environmental (dis)amenities when treatment and control groups are not clearly defined. Their technique has recently been used to estimate the impact of brownfield remediation (Haninger, Ma, and Timmins 2014) and shale gas developments (Muehlenbachs, Spiller,

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[7] Since the quadratic Box-Cox is still computationally intensive and the coefficients are difficult to interpret, semilog and linear Box-Cox models are commonly used.

and Timmins 2014).[8] Parmeter and Pope (2013) provide a thorough overview of the difference-in-differences method and other quasi-experimental techniques. By differencing over time, the difference-in-differences method controls for time-invariant unobservables, just like the fixed effects and repeat sales methods, but also overcomes problems with time-varying unobservables with the "common trends" assumption.[9]

Mastromonaco (2014) and Bajari et al. (2012) both propose methods for reducing bias caused by time-varying spatially correlated unobservables. Mastromonaco (2014) includes census tract–year fixed effects that allow the effect of unobservables at the neighborhood level to vary over time in a repeat sales model. Bajari et al. (2012) also use a repeat sales model but exploit information contained in the residual from the first sale to learn about the characteristics of the house that the researcher cannot observe directly. In contrast, the data used in this study have house characteristics at the time of each sale and allow for control of time-varying housing characteristics that are typically unobservable. In this study the results below show that the unobservables at the neighborhood level that are correlated with proximity to a communication antenna are time invariant and are adequately controlled for using spatial fixed effects.

III. DATA ON HOUSING AND ANTENNAS

Housing data covering a period of 12 years from 2000 to 2011 were extracted from two multiple listing services that serve the Louisville and Elizabethtown areas in central Kentucky.[10] The housing data contain an extensive set of structural housing characteristics, closing date, and sales price for every property sold. All property addresses were geocoded, and a standardized address and latitude and longitude were assigned to each property.[11] This standardized address is used to identify houses that are sold multiple times.

These data are much richer than data extracted from a local property valuation administrator or data from DataQuick that are commonly used. While data from each of those sources identify properties that are sold more than once, the structural housing characteristics are recorded only for the most recent transaction. The data used here identify properties that are sold more than once during the sample period and record the structural housing characteristics each time the property is sold. This detail allows for a check of the assumption that structural housing characteristics are constant over time, an assumption that is often made when using the repeat sales method.

Data for the communication antennas come from the Federal Communication Commission's (FCC) Antenna Structure Registration database.[12] This database includes all communication antennas in the United States that are registered with the FCC. All antennas that may interfere with air traffic must be registered with the FCC to make sure the lighting and painting requirements are met. These data contain antenna characteristics such as dates of construction and demolition, latitude and longitude, antenna height, and antenna type. It is possible there are antennas located in the study area that are not registered, but this is

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[8] Muehlenbachs, Spiller, and Timmins (2014) use a difference-in-difference-in-differences model. They use the Linden and Rockoff (2008) technique to find the distance at which shale gas developments do not impact property values, but also use the local public water service area to define a second treatment group. Similar to owners of land where shale gas wells are drilled, owners of land where communication antennas are located receive payments from the antenna's owner.

[9] In this study, a majority of communication antennas were built several years before the property was sold, making a visual check of the "common trends" assumption difficult.

[10] Please contact the author regarding any questions about the multiple listing service data.

[11] One issue with geocoding addresses is that the coordinates will correspond to the location on the street where the property is located and not the exact coordinates of the actual house; Filippova and Rehm (2011) were able to overcome this using the coordinates where the home was located within the plot. In the current study, properties that were not assigned a standardized address and a unique latitude and longitude were excluded from the final sample. Properties with less than 500 square feet or more than 10,000 square feet, or zero bedrooms or zero full baths were also dropped.

[12] Antenna Structure Registration database available at http://wireless.fcc.gov/antenna/index.htm?job = uls_transaction&page = weekly.

rare. Since the construction date of each antenna needs to be known to ensure the antennas located near houses were standing when the properties sold, antennas that did not include a construction date were dropped.[13] Google Earth[14] was used to verify whether not an antenna was standing when the property sold if there was a dismantled date recorded. Since the images include the date the image was captured, it was possible to identify whether the antenna was standing when the property sold.[15]

ArcGIS[16] was used to determine several location-specific characteristics. They include (1) the census tract in which each house is located, (2) the census block group in which each house is located, (3) distance to the nearest communication antenna, (4) distance to the nearest parkway/interstate, (5) distance to the nearest railroad, and (6) distance to the Fort Knox military base. Since the visual disamenity of communication antennas is the focus of this study, all proximity measures were calculated using straight-line distances. All antennas within a 10-mile radius of each property that were standing when the property was sold were identified. This information was used to determine the number of antennas located within specified distances from each property. In addition, using the Viewshed tool in ArcGIS, a variable was created that is distance to the nearest visible communication antenna for each house in the sample. This variable facilitates isolation of the impact of visual pollution (see Paterson and Boyle 2002; Jensen, Panduro, and Lundhede 2014). This variable is used along with (unconditional) distance for comparison.

Averages or shares for the housing characteristics are given in Table 1. The typical house sold for $183,609 (in 2011 dollars), has three bedrooms and two full bathrooms, is 1,655 square feet in size, has a lot size of about eight-tenths of an acre, and is 33 years old. Holding all else constant, the owner of a communication antenna will attempt to locate the antenna in an area that minimizes the antenna owner's cost. To check if antennas are located in areas where property values are low to begin with, Table 1 also shows averages for houses within and beyond 4,500 feet of an antenna.[17] Houses within 4,500 feet of an antenna sell for $32,991 (16%) less than houses more than 4,500 feet away, have slightly fewer bedrooms and bathrooms, are smaller, and are on smaller lots. The most notable difference is that houses within 4,500 feet of an antenna are about 18 years older on average than houses more than 4,500 feet away from an antenna. The differences in means between houses within and beyond 4,500 feet are statistically different from zero at usual levels for all characteristics except for Within 1 Mile Ft. Knox. It appears that communication antennas are in fact located in areas where properties are less valuable. While most of the difference in sales prices for houses within and beyond 4,500 feet of an antenna can be explained by differences in the types of houses, the primary focus of this study is controlling for differences that are unobservable. The precise location information for each house provided in the data is used to control for these unobservables.[18]

For the full sample of houses, the median distance to the nearest visible antenna when a house is sold is 4,459 feet, or approximately 0.84 miles. The mean distance is 5,959 feet (1.3 miles) with a standard deviation of 5,334

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[13] Since the earliest construction year in the sample of antennas is 1927 and the latest 2011, it cannot be assumed that the absence of a construction date means the antennas with missing dates were built before the year 2000 and can be included in the final sample.

[14] See www.google.com/earth/ for access to images.

[15] This was a concern for only a handful of antennas. Multiple antennas were assigned the same coordinates, and it was determined that this corresponded to multiple antennas being mounted on the same structure. Some demolition dates indicated that an antenna was removed, and some demolition dates indicated that the actual structure was taken down. Being dismantled refers to the latter.

[16] See www.esri.com/software/arcgis.

[17] 4,500 feet is approximately the median value of distance to the nearest standing antenna in this sample. Distance in thousands of feet is used in the analysis that follows.

[18] A regression of the number of communication antennas in a census tract on the median sales price and census tract demographics suggests that the number of antennas in a census tract is negatively correlated with property values. However, even though the coefficient has the expected sign, the coefficient is not statistically different from zero at conventional levels, and the median sales price and demographics explain only 8% of the variation in the number of communication antennas in a census tract.

TABLE 1
Mean or Share for Structural Housing Characteristics

Variables	All	Less than 4,500 ft	Greater than 4,500 ft
Sales price (2011 dollars)	183,609	167,235	200,226
Bedrooms	3.241	3.161	3.323
Full bathrooms	1.811	1.687	1.937
Partial bathrooms	0.368	0.346	0.39
Square feet of living space	1,655	1,573	1,739
Lot size (acres)	0.82	0.383	1.263
Lot size missing	0.046	0.044	0.049
Has < in lot dimensions[a]	0.127	0.149	0.105
Has > in lot dimensions[a]	0.003	0.003	0.004
Age (years)	33.153	42.078	24.096
Age unknown	0.01	0.006	0.014
Fireplace	0.479	0.474	0.484
Basement	0.602	0.613	0.59
Finished basement	0.175	0.153	0.197
Central air	0.909	0.898	0.921
Brick exterior	0.346	0.322	0.37
Vinyl exterior	0.162	0.157	0.168
Metal roof	0.01	0.006	0.013
Composition roof	0.94	0.944	0.935
Ranch style	0.447	0.409	0.485
Modular style	0.014	0.004	0.024
Cape cod style	0.084	0.102	0.066
Carport	0.057	0.066	0.049
Garage	0.663	0.657	0.668
One-car garage	0.169	0.209	0.128
Multiple-car garage	0.563	0.494	0.632
Within 1 mile parkway/Interstate	0.485	0.629	0.338
Within 1 mile railroad	0.511	0.569	0.452
Within 1 mile Ft. Knox	0.014	0.014	0.014
Sample size	142,161	71,604	70,557

[a] The lot dimensions indicated the lot size was less (greater) than the listed size.

feet. Only 0.4% of houses are within 500 feet of the nearest visible antenna, while 9.5% of the houses in the sample have a visible antenna within 2,000 feet. Some houses are likely affected by the presence of multiple antennas. For example, there are 108 houses that have two visible antennas between 500 and 1,000 feet and 6 that have three antennas within that same radius. This variation in antenna density means that estimating the disamentity value caused by communication antennas using distance to the nearest antenna could be biased due to the presence of multiple antennas. Estimates would tend to be biased upward, because all the value of the disamenity would be attributed to the nearest antenna when it should be attributed to the combination of antennas.

Before moving to estimation of any disamenity value of antennas, it is worth addressing an overall concern about housing market analysis during the Great Recession. The concern is how an equilibrium framework such as that described by Rosen (1974) can produce misleading results during a period of disruption.[19] Without question, housing prices declined between 2006 and 2009, but as Carson and Dastrup (2013) report, there was considerable spatial variation. Across metropolitan areas, housing prices declined none at all to more than 60%. The four-quarter percentage change in the Federal Housing Finance Agency's housing price index[20] is shown in Figure 2 for the study area and the Los Angeles and Miami metropolitan statistical areas (MSAs). Even though the Louisville MSA was affected by the recent housing crisis,

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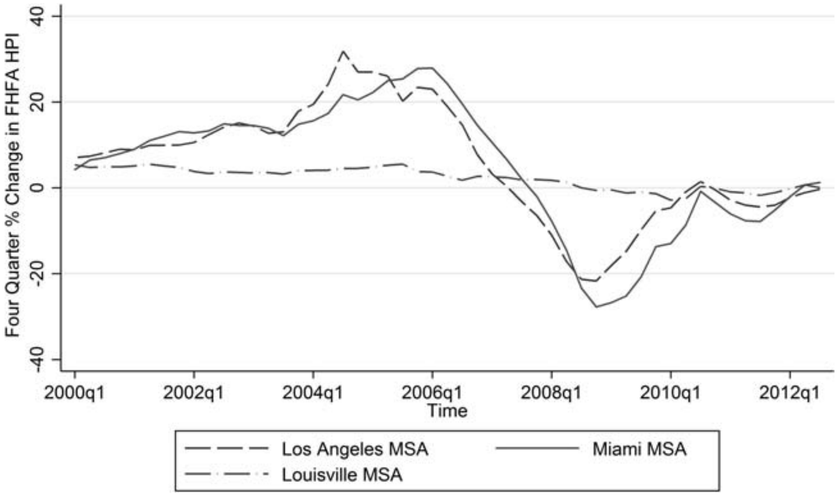
[19] This issue is discussed in detail by Boyle et al. (2012).

[20] Federal Housing Finance Agency Housing Price Index data available at www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index.aspx.

FIGURE 2
Four Quarter Percent Change in the Federal Housing Finance Agency Housing Price Index in the Los Angeles, Louisville, and Miami Metropolitan Statistical Areas



house prices remained relatively stable compared to the larger MSAs that were affected the most. This stability alleviates concerns that the results presented below are being affected by a rapidly changing and unstable housing market.

Changes in census tract demographics[21] from 2000 and 2010 for the study area were also compared to changes for the entire United States. The only notable difference is that unemployment more than doubled nationally, while there was only a 62% increase in the study area. For the entire United States, the percentage change in the number of people who moved in from out of state fell by 71%, while it increased by 12% in the study area; since the study area contains the Fort Knox military base, the above average number of out-of-state movers is to be expected.[22]

Because there is a concern that antennas could be located in areas with not only lower property values but also disadvantaged populations, demographics for census block groups that contain antennas were compared to those within the same census tract that do not have any antenna structures, for the entire state of Kentucky in 2010. While small differences exist, none are significant at conventional levels. Table 1 shows that houses near these antennas sell for less than homes farther away; however, these differences do not appear to be driven by differences in demographic characteristics.[23]

IV. EMPIRICAL MODEL

To determine the impact proximity to an antenna structure has on property values, hedonic property value models and quasi-experimental methods are used. The first regressions rely on cross-sectional variation in distance to the nearest antenna and do not exploit the panel aspect of the data. The second

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[21] Census data available at http://factfinder.census.gov.

[22] A regression of the change in the number of communication antennas in a census tract on the percentage changes in demographic characteristics in the same tract suggests that changes in demographics are not leading to significant changes in the number of communication antennas in an area. There were statistically significant coefficients for median income, unemployment, percentage of the population that owns their home, and the percentage of the population with a bachelor's degree or higher. However, the changes in these characteristics required to cause one additional antenna to be constructed or dismantled are extremely large. For example, it would take a 1,067% increase in unemployment to lead to the dismantling of one antenna.

[23] Note that this calculation is possible only for census tracts that have at least one block group without antennas.

set of regressions exploits the panel aspect of the data to reduce the potential bias caused by time-invariant unobservables. The data cover a period of 12 years, with communication antennas being built and dismantled throughout the period as well as in between sales of the same property. These changes allow for estimation of the traditional cross section specifications as well as the repeat sales and difference-in-differences specifications that are becoming more prevalent in the hedonic literature (Gayer, Hamilton, and Viscusi 2002; Linden and Rockoff 2008; Parmeter and Pope 2013; Haninger, Ma, and Timmins 2014; Muehlenbachs, Spiller, and Timmins 2014; Bajari et al. 2012).

Cross-Section Specification and Proximity Measures

Following Kuminoff, Parmeter, and Pope (2010) and Heintzelman and Tuttle (2012), a semilog specification with spatial fixed effects is used to address the potential bias caused by time-invariant, spatially correlated unobservables. The first specification is

$$\ln P_{ijt} = \mathbf{Z}_{ijt}\beta + \mathbf{X}_{ijt}\delta + \lambda_t + \gamma_j + \epsilon_{ijt}, \qquad [2]$$

where $\ln P_{ijt}$ is the natural log of the price of house i at location j at time t, $\mathbf{Z}_{ijt}$ is the set of variables describing proximity to the nearest antenna structures, $\mathbf{X}_{ijt}$ includes an extensive set of structural housing characteristics, λ_t are year-month time dummy variables, γ_j are spatial fixed effects, and ϵ_{ijt} is the error term. To demonstrate the importance of including the spatial fixed effects, equation [2] is estimated without spatial fixed effects and again with census tract or census block group fixed effects. If there are unobserved spatial characteristics that are correlated with the proximity variables, β in equation [2] should be more precisely estimated when smaller geographic fixed effects are used.

Distance to communication antennas is measured using a continuous quadratic measure of distance to the nearest visible antenna that was standing when the property sold.[24] The spatial fixed effects ensure that this continuous measure of distance is measuring the impact of a nearby antenna and not proximity to an area that may be a magnet for communication antennas. As a robustness check, the inverse of distance to the nearest antenna that was standing when the property sold is also used.

As an additional robustness check, proximity is measured using 500-foot distance rings that include a dummy variable equal to 1 if a communication antenna is located within some specified distance. The dummy variable method is the primary specification used by Heintzelman and Tuttle (2012) and allows for a high degree of nonlinearity in the disamenity caused by these antennas. A shortcoming of this method is that the size of the distance rings and the distance used as the omitted category is somewhat arbitrary. If properties are affected by the presence of multiple antennas, the dummy variable approach will overestimate the disamenity caused by communication antennas. Since multiple properties in the sample have more than one antenna nearby, proximity is also measured using the number of antennas within each ring. This is the method used by Mastromonaco (2014) to estimate the impact of Superfund sites on property values in Los Angeles.

Panel Analysis

One strategy for removing time-invariant unobservables is to exploit the variation in distance to the nearest antenna for properties that sell multiple times. During the study period, new antennas were constructed and old antennas were dismantled. These changes create variation in distance to the nearest antenna over time for the same property. This approach eliminates any time-invariant unobservables that may be correlated with the proximity variables and is the primary method used by Gayer, Hamilton, and Viscusi (2002), Heintzelman and Tuttle (2012), Mastromonaco (2014), and Bajari et al. (2012). The following regression is estimated:

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[24] Banfi, Filippini, and Horehájová (2008) and Bond (2007a, 2007b) estimate the impact of cell phone towers on property values, but their specifications do not fully account for endogeneity of tower location and correlated unobservables.

$$\ln P_{it} - \ln P_{it'} = (z_{it} - z_{it'})\beta + (\mathbf{X}_{it} - \mathbf{X}_{it'})\delta + \lambda_t + \epsilon_{it} - \epsilon_{it'}, \qquad [3]$$

where $\ln P_{it}$ is the natural log of the price of house i at time t, z_{it} is the distance to the nearest standing antenna at time t, and $\mathbf{X}_{it}$ are structural housing characteristics that may vary over time. Following Gayer, Hamilton, and Viscusi (2002), λ_t is a set of year variables equal to –1 if the year indicates the first year the property sold, 1 if the year indicates the year of the last sale, and 0 for all other sales.[25] This allows for appreciation in housing values over time. ϵ_{it} is the error term. This specification is different from the repeat sales model that is typically estimated. In the typical repeat sales model, only the proximity variables that measure distance to the nearest antenna would be allowed to vary over time, while the structural housing characteristics are assumed to be constant. Several recent studies use data from sources that do not record the structural housing characteristics each time a house is sold and make the assumption of constant structural characteristics (Heintzelman and Tuttle 2012; Mastromonaco 2014; Bajari et al. 2012). Equation [3] will be estimated with and without the changing structural housing characteristics to control for changes and determine how sensitive the estimate of β is to the assumption of constant structural characteristics.

There are shortcomings when using the repeat sales approach. There is the possibility that the unobservables are not time invariant. Kuminoff, Parmeter, and Pope (2010) show that when the omitted spatial characteristics are time varying, the bias in the first-differenced estimates increases substantially. Since not all properties are sold multiple times, the repeat sales approach leads to much smaller sample sizes. In addition, properties that sell multiple times may be systematically different than properties that sell only once. Properties that turn over multiple times may be repeatedly priced below market value, or more importantly, the local disamenity has an above-average effect on those properties. With an extensive list of housing characteristics at the time of all sales, the number of time-varying unobservables is smaller than in studies that do not have house characteristics at the time of sale each time the property is sold.[26]

V. RESULTS

Cross-Section Results

Results that use a continuous measure of distance to the nearest visible antenna are reported in Table 2, Panel A. In column (1), census tract fixed effects are included, and the results show that holding constant the characteristics of the house, the year, and month the property was sold, and the area in which the property is located, consumers are willing to pay a premium to be located farther away from a communication antenna. The estimates in column (1) show that the sales price of a house is increasing at a rate of approximately 0.74% at a distance of 1,000 feet and at a rate of about 0.68% at 2,500 feet. No effect is found beyond 21,093 feet (approximately 4.0 miles). Interestingly, specifications (not shown) that do not include any spatial fixed effects indicate that houses with communication antennas nearby sell for more, not less, than houses where the nearest antenna is farther away. Column (2) includes census block group fixed effects, which are more precise than the census tract fixed effects used in column (1). These estimates suggest that the sales price of a house increases at a rate of about 0.57% at a distance of 1,000 feet, and a rate of 0.53% at 2,500 feet. No effect is found beyond 21,583 feet (approximately 4.1 miles). Even though the effect of distance is identified by variation in distance within a smaller geographic area, the specification using census block group fixed effects provides

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[25] Bailey, Muth, and Nourse (1963) introduce this method of estimating a price index using a repeat sales framework. The first period (year 2000) is the base year, and the remaining coefficients can be interpreted as the log price index.

[26] A difference-in-differences specification was also used to mitigate the effects of time-invariant unobservables. This technique is discussed in detail by Parmeter and Pope (2013) and used by Linden and Rockoff (2008), Muehlenbachs, Spiller, and Timmins (2014), and Haninger, Ma, and Timmins (2012) in difference-in-differences. Treatment and control groups were identified using the method of Linden and Rockoff (2008).

TABLE 2

Cross-Section Results for Antenna Impact Using Continuous Measures of Distance

Variable[a]	(1) ln(Sales price)	(2) ln(Sales price)
Panel A		
Distance to nearest visible antenna	0.00772*** (0.00150)	0.00600*** (0.00132)
Distance^2 to nearest visible antenna	− 0.000183*** (3.49e–05)	− 0.000139*** (2.99e–05)
Constant	10.51*** (0.0309)	10.24*** (0.0195)
Observations	141,208	141,208
R-squared	0.853	0.862
Panel B		
Distance to nearest antenna	0.0104*** (0.00187)	0.00888*** (0.00173)
Distance^2 to nearest antenna	− 0.000323*** (5.81e–05)	− 0.000284*** (5.74e–05)
Constant	10.50*** (0.0307)	10.23*** (0.0199)
Observations	142,161	142,161
R-squared	0.853	0.862
Panel C		
Inverse distance to nearest visible antenna	− 0.0359*** (0.00886)	− 0.0285*** (0.00743)
Constant	10.56*** (0.0299)	10.28*** (0.0187)
Observations	141,208	141,208
R-squared	0.853	0.862
Year-month dummies	Yes	Yes
Tract fixed effects	Yes	No
Block group fixed effects	No	Yes

Note: Distances to antennas are measured in thousands of feet. Standard errors are clustered at the level of included fixed effect.

[a] Also included in each regression are bedrooms, full bathrooms, partial bathrooms, square feet, square feet^2, lot size, lot size missing, age, age^2, age unknown, fireplace, basement, finished basement, central air, exterior type, roof type, style of home, garage, carport, within 1 mile parkway/interstate, within 1 mile railroad, and within 1 mile Ft. Knox.

*** $p < 0.01$.

estimates that are more precisely estimated than the census tract specification. This result provides further evidence that there are spatially correlated unobservables that are negatively correlated with distance to a communication antenna.[27]

Panel B uses the same quadratic distance specification but uses the more naive measure of distance to the nearest antenna that does not take into account whether the nearest antenna is visible from the house. While the effect is similar, it is estimated with less precision than the specification that accounts for visibility of the nearest antenna. For approximately 5% of the houses in the sample, the nearest antenna is not visible, and that fact produces measurement error in this specification.[28]

As a robustness check, the same specifications are estimated using the inverse of distance to the nearest visible antenna. These re-

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[27] Regressions were estimated that included the percentage of rural residents in a census tract instead of census tract fixed effects. The results show that the sales price of a house is decreasing as the number of people living in rural areas increases, and that proximity to a communication antenna has a positive effect on the sales price of a house in highly urban areas, and a negative effect in more rural areas. This is consistent with the idea that antennas in more urban areas are more likely to be disguised than in rural areas, where the antennas structures tend to be much larger. Urban areas have multiple structures such as tall buildings, smoke stacks, clocks, and church steeples that antennas can be located on or around. The R^2 for the urban/rural specification was 0.72 compared to 0.85 in the census tract specification in Table 2.

[28] As an additional robustness check, a specification was estimated that uses distance to the nearest tower-type antenna. These structures are larger and are visible at greater distances than the smaller antenna structures and are expected to have a larger effect on property values and have an effect at greater distances if they are visible. If the estimated effect is larger than when all antennas are considered, this provided additional evidence that households are aware of this visual disamenity and respond rationally (Pope 2008; Currie et al. 2015). As expected, the results show that the tower-type antennas lead to a larger decrease in property values and have an effect farther away.

TABLE 3

Cross-Section Results of Antenna Impact Using 500-Foot Distance Rings: Any Antenna and Number of Antennas

Variable[a]	(1) ln(Sales Price) 1 if Within	(2) ln(Sales Price) Number Within
0 to 500	− 0.0752*** (0.0232)	− 0.0494** (0.0206)
500 to 1,000	− 0.0613*** (0.0134)	− 0.0390*** (0.0112)
1,000 to 1,500	− 0.0630*** (0.0109)	− 0.0417*** (0.00917)
1,500 to 2,000	− 0.0620*** (0.00987)	− 0.0417*** (0.00691)
2,000 to 2,500	− 0.0512*** (0.00918)	− 0.0289*** (0.00650)
2,500 to 3,000	− 0.0450*** (0.00796)	− 0.0286*** (0.00538)
3,000 to 3,500	− 0.0428*** (0.00759)	− 0.0288*** (0.00473)
3,500 to 4,000	− 0.0343*** (0.00652)	− 0.0248*** (0.00456)
4,000 to 4,500	− 0.0128** (0.00593)	− 0.0167*** (0.00425)
Constant	10.30*** (0.0194)	10.31*** (0.0208)
Observations	141,208	141,208
R-squared	0.862	0.863
Year-month dummies	Yes	Yes
Tract fixed effects	No	No
Block group fixed effects	Yes	Yes

Note: Standard errors are clustered at the census block group.

[a] Also included in each regression are bedrooms, full bathrooms, partial bathrooms, square feet, square feet^2, lot size, lot size missing, age, age^2, age unknown, fireplace, basement, finished basement, central air, exterior type, roof type, style of home, garage, carport, within 1 mile parkway/interstate, within 1 mile railroad, and within 1 mile Ft. Knox.

** $p < 0.05$; *** $p < 0.01$.

sults are shown in Table 2, Panel C. When census tract fixed effects are included, the estimates show that the sales price of a house is increasing at a rate of approximately 3.6% at a distance of 1,000 feet, and at a rate of about 0.57% at 2,500 feet. When census block group fixed effects are included, the estimates show that the sales price of a house is increasing at a rate of about 2.9% at a distance of 1,000 feet, and a rate of 0.46% at 2,500 feet. Again, the effect is estimated more precisely as more precise fixed effects are included. Overall, the results do not appear to be extremely sensitive to functional form when using a continuous measure of distance.

Results from an alternative specification that uses 500-foot distance rings are shown in Table 3. Column (1) indicates whether an antenna is located within a specified radius, and column (2) estimates the marginal effect of an additional antenna within the same radius by using the density of nearby antennas. The results suggest that houses located near an antenna sell for less than a comparable house farther away and that both distance to the nearest antenna and the density of nearby antennas have a significant effect on property values. In both specifications, the effect of communication antennas on property values diminishes almost monotonically with distance.[29]

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[29] Bond and Wang (2005) and Bond (2007a) estimate the impact of cell phone towers on property values in New Zealand, but the studies have limitations. The first lacks precise location information for the houses and uses street name fixed effects as a proxy for distance to a tower. The second geocodes houses, but the model is misspecified. They use a continuous distance measure but set distance equal to zero if the house sold before the tower was constructed. Bond's (2007b) is the only study found that uses U.S. data. It is limited to sales from one area of Orange County, Florida, and includes the latitude and longitude of each property in each regression. Banfi, Filippini and Horehájová (2008) look at the impact of cell phone towers on rents in Zurich Switzerland and find a significant decrease in rents of about 1.5% on average. Filippova and Rehm's (2011) is the most recent study. They use data from the Auckland region of New Zealand and also use distance bands and a continuous distance measure. Their distance band specification yields insignificant results, and the coefficient of the continuous distance measure has a significant, but wrong-signed coefficient. They report a negative but insignificant impact on property values. The authors fail to consider the interaction terms between distance and their location variables. Given they use 50-meter increments for their distance bands, it is likely there is not enough variation within each band to identify any impact.

TABLE 4

Results Using Repeat Sales and a Continuous Measure of Distance: All Repeat Sales and Sold Only Twice

Variable	(1) Δ ln(Sold price)	(2) Δ ln(Sold price)
Panel A		
Δ Distance to nearest visible antenna[a]	0.00537*** (0.000924)	0.00200** (0.000941)
Constant	0.0543*** (0.00308)	0.152*** (0.00527)
Observations	29,759	20,871
R-squared	0.102	0.144
Panel B		
Δ Distance to nearest visible antenna[a]	0.00546*** (0.000869)	0.00254*** (0.000861)
Δ Bedrooms	0.0781*** (0.00562)	0.0613*** (0.00628)
Δ Full bathrooms	0.171*** (0.00802)	0.169*** (0.00912)
Δ Partial bathrooms	0.105*** (0.00959)	0.111*** (0.0114)
Δ Finished basement	0.0211*** (0.00385)	0.00992** (0.00458)
Δ Central air	0.255*** (0.00979)	0.243*** (0.0116)
Δ Carport	0.0585*** (0.0145)	0.0397*** (0.0151)
Δ Garage	0.0152* (0.00783)	0.0220** (0.00914)
Observations	29,759	20,871
R-squared	0.202	0.231
All repeats	Yes	No
Sold twice	No	Yes

[a] Distances to antennas are measured in thousands of feet. Standard errors are clustered at the property level.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

The results that account for number of antennas (shown in Table 3, column (2)) are consistent with the argument made by Mastromonaco (2014) that considering only distance to the nearest site will lead to biased estimates if there are multiple sites that could adversely affect a property's sales price. As is expected, adding an additional antenna near a residential property has a smaller effect than an antenna being located near a property that did not previously have one nearby. Since the absolute value of the point estimate of almost every coefficient in column (2) of Table 3 is smaller than the corresponding coefficient in column (1), the estimates that measure proximity with distance to the nearest site are likely biased. To further explore this possible effect, a specification (not shown) was estimated that included both distance to the nearest visible antenna along with the density of nearby antennas, using 500-foot rings. Although the effect of density of nearby antennas remained significant, the effect of distance to the nearest antenna was not significant at conventional levels.

Panel Results

Results from the first repeat sales specification that assumes the structural housing characteristics are constant over time are shown in Table 4, Panel A. In this specification, the change in sales price is assumed to be a function of the change in distance to the nearest visible antenna and a set of year dummy variables that are equal to –1 if the year indicates the time of the first sale, 1 if the year indicates the year of the last sale, and 0 for all other sales. Comparing the change in sales price for houses that are sold more than once eliminates any bias that could be caused by time-invariant spatially correlated unobservables.

Comparing columns (1) and (2) for each cross-section specification in Table 2 shows that as more precise spatial fixed effects are used, the estimated effect of communication antennas on the sales price of a house is smaller and more precisely estimated. This indicates that the spatially correlated unobservables are negatively correlated with proximity to an antenna. If this is true, and the unobservables are time invariant, the repeat sales estimates of the impact communication antennas have on property values should be similar to the estimates using the more precise census block group fixed effects.

The results in each column of Table 4 are consistent with this hypothesis. Column (1) includes all houses that sold more than once during the sample period. For every 1,000-foot change in distance to the nearest antenna, on average, the sales price of a house increases by 0.54%. Column (2) includes the set of houses that sold only twice during the 12 years the data cover. Since repeat sales are identified by the standardized address that was assigned to each property, limiting the sample to houses that sold only two times reduces the chance of including houses that are being considered repeat sales due to a coding error. Even though the sample size is reduced by 8,888 observations compared to the sample of all repeat sales, the R^2 increases by 0.042, and the effect of distance is still precisely estimated. In this specification, for every 1,000-foot change in distance to the nearest antenna, on average, the sales price of a house increases by 0.20%.

Of the 29,886 houses that sold more than once, a nontrivial number experienced a change in a major structural characteristic between sales. For example, 4,316 (17%) of houses had a change in the number of bedrooms between sales. The repeat sales results in Table 4, Panel B are based on relaxing the assumption that structural housing characteristics are constant over time. As is expected, including the changes in structural housing characteristics leads to a higher R^2, increases in each characteristic lead to a larger positive change in sales price, and the effect of distance is more precisely estimated. This result suggests that the change in distance to the nearest antenna between sales of the same property is not completely orthogonal to the change in housing characteristics, an assumption that must be made when detailed sales data are not used. When changing structural housing characteristics are accounted for, the estimated impact is slightly larger than the estimate in Panel A. While these estimates are not statistically different at conventional levels, a larger effect when the changing structural housing characteristics are included is consistent with the results from Bajari et al. (2012) that show ignoring time-varying correlated unobservables leads to underestimates of the benefits of pollution reduction.[30]

VI. DISCUSSION AND CONCLUSIONS

Overall, the results from the preferred specifications that include spatial fixed effects show that houses located near communication antennas sell for less on average than comparable houses located farther away from an antenna. There are a few important points to note about these results. First, regardless of the specification, time-invariant spatially correlated unobservables bias the cross-sectional estimates of the disamenity associated with nearby communication antennas when no controls for neighborhood characteristics are included. When spatial fixed effects are not included, the results suggest that houses near communication antennas sell for more, not less, than a similar house farther away from an antenna. When spatial fixed effects are included to capture the effect of time-invariant spatially correlated unobservables, each specification used indicates that houses near communication antennas sell for less than a similar house located farther away from an antenna. When the more precise census block group fixed effects are included, the estimated reduction in sales price caused by a communication antenna becomes smaller and is estimated more precisely in each of the cross-section specifications. This effect reinforces the importance of carefully controlling for

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[30] Estimates from the difference-in-differences specification show that houses within 2,000 feet of an antenna at the time they were sold sell for about 3.3% less than a comparable house more than 2,000 feet away from an antenna at the time it was sold. When the equilibrium price function with respect to structural housing characteristics is allowed to change over time, an effect of about 2.2% is found but is not statistically significant at conventional levels. Since many houses in the sample are affected by the presence of multiple antennas, defining treatment and control groups using the method of Linden and Rockoff (2008) that uses distances to the nearest standing and not-standing antennas may not be appropriate.

spatially correlated unobservables that are correlated with proximity to a localized disamenity.

Consistent with the conjecture made by Mastromonaco (2014), estimating the effect of communication antennas on property values using distance to the nearest antenna is likely biased due to the presence of multiple nearby antennas. The results in column (2) of Table 3 indicate that a house located within 500 feet of an antenna sells for 7.5% less than a similar house more than 4,500 feet away from its nearest antenna. The results in column (2) of Table 3 show that adding an additional antenna within 500 feet of a house leads to a smaller reduction in sales price of 4.9%.

The results also suggest that the omitted spatial characteristics correlated with proximity to a communication antenna are time invariant and are being captured by the census block group fixed effects. First, the effect communication antennas have on nearby properties is smaller and is estimated more precisely when census block group fixed effects are used compared to the census tract estimates. This confirms that there are unobservables spatially correlated with distance to a communication antenna. Second, the repeat sales method eliminates any bias caused by time-invariant unobservables and provides results that are smaller than the cross-sectional estimates that include census block group fixed effects. Since the antennas are located in areas where property values are lower, the repeat sales specification that eliminates all time-invariant unobservables should yield results with the smallest amount of bias. Since the sample of houses that are sold multiple times may not be a random sample of all houses, some bias could still exist.

The best estimate of reduction in sales price caused by communication antennas shows that the sales price of a house is increasing at a rate of about 0.57% ($1,047) at a distance of 1,000 feet from the nearest antenna (Table 2, Panel A, column (2)). This suggests that a property located within 1,000 feet of the nearest antenna at the time of sale will sell for 1.82% ($3,342) less than a similar house that is 4,500 feet from the nearest antenna. In this specification, time-invariant spatially correlated unobservables are controlled for with census block group fixed effects. The repeat sales results in Table 4 provide additional evidence that the spatially correlated unobservables are being captured by the fixed effects. These estimates of the disamenity associated with communication antennas controls for time-invariant unobservables at the property level and suggests that a property located within 1,000 feet of an antenna will sell for 0.89% ($1,634) less than a similar house that is 4,500 feet from the nearest antenna (Panel B, column (2)). However, since the repeat sales are identified by matching a standardized address, these results could be sensitive to measurement error.

This effect is smaller than the estimated reduction caused by similar disamenities. Kroll and Priestley (1992) provide a review of the literature concerning overhead transmission lines and property values through the early 1990s. They find that in studies where a significant decrease was found, the decrease in property values typically fell in the range of 2% to 10%, and the effect diminished beyond a few hundred feet. Hamilton and Schwann (1995) estimate the impact of high voltage electric transmission lines have on property values, but primarily focus on the importance of using the correct functional form. They find that properties adjacent to a line lose about 6.3% of their value, but more distant properties are hardly affected. Using a repeat sales model, Heintzelman and Tuttle (2012) find that having a wind turbine located 0.5 miles away leads to a reduction in sales price from 8.8% to 15.81%.

The preferred specification for estimating the disamenity associated with communication antennas is the continuous measure of distance using census block group fixed effects (Table 2, Panel A, column (2)). These results imply that a property with an antenna located within 1,000 feet at the time of sale will sell for 1.82% ($3,342) less than a similar house that is 4,500 feet from the nearest antenna. In this sample, there are 3,031 houses within 1,000 feet of an antenna structure. Using the preferred repeat sales specification as a lower bound, if each antenna within 1,000 feet of a property were moved to a distance of 4,500 feet, there would be an aggregate increase in sales price of $4.95 million. The best estimate suggests the aggregate increase would be $10.13 million. These values should be compared to the cost of camouflaging or disguising communication antennas near residential properties to mitigate the effect they have on property values.

In areas where antennas are highly visible (Figure 1, upper photo), there is a potential externality caused by these antennas. If antennas are constructed near residential properties after the homeowner purchases the property, those houses suffer a small but nontrivial decrease in their property value and their owners are unlikely to be compensated by the land owner where the antenna is located or the owner of the antenna. Camouflaging is one solution to this problem that has been implemented in some areas. Camouflaged towers blend in with the landscape or are constructed in already standing structures such as church steeples and clock towers. Such developments will mitigate the disamenity associated with communication antennas and reduce the cost of convenience.

Acknowledgments

The authors thank Adib Bagh, Spencer Banzhaf, Karen Blumenschein, William Hoyt, Matthew Kahn, Lynn Lewis, Gary Painter, Christopher Parmeter, Daren Pope, Frank Scott, Christopher Timmins, and an anonymous referee for helpful comments on earlier drafts, and the UCLA Ziman Center for Real Estate for partial support. We also want to thank Trey Nunn for providing us with valuable GIS support.

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