Neighborhood Impacts on Land Use Change:

A Multinomial Logit Model of Spatial Relationships

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The following paper is a pre-print and the final publication can be found in
Annals of Regional Science, 42 (2):321-340, April 2008.

Abstract Models of land use change are central to forecasting urban futures. This work models the related processes of parcel subdivision and land development using a pair of recent GIS-encoded Austin, Texas land use maps. Based on binomial and multinomial logit models of subdivision and use change, a variety of lagged explanatory variables offer insight into land dynamics. These models recognize variables such as parcel size and shape, slope, transit and CBD access, distance to the nearest highway, and zoning policies, as well as each parcel's "neighborhood" attributes. Neighborhood conditions offer substantial predictive power, though such effects seem inconsequential beyond 2 miles. Various spatial tendencies in land use development are identified. Model applications present a perspective on Austin's land use future. Comparisons of predicted and actual land use changes (in 2005) reveal strengths and limitations of the models.

JEL: R14 R11

We wish to thank the Environmental Protection Agency for financially supporting this study under its Star Grant program. The multi-team project is titled "Predicting the Relative Impacts of Urban Development Policies and

1. Introduction

Land use patterns tell a story of human activity and environmental evolution, and future settlement patterns are of interest to many. Changes in land use alter the distribution of vegetation, homes and workplaces, and consequently influence biogenic and on-road mobile emissions. Numerous studies have shown that land use patterns and intensities have a direct impact on travel behavior (e.g., Frank and Pivo 1994, Kockelman 1997, Kitamura et al. 2001, Srinivasan 2002). Planners, policymakers, developers, transportation engineers, air quality modelers and others wish to anticipate demand, in order to ensure adequate provision of public and private services (such as schools and highways) along with policies that guide demand while mitigating negative environmental impacts (such as congestion and pollution).

The forces that drive land use change range from climate to topography, public policies to highway access, and interact in an intricate way (e.g., Veldkamp and Lambin 2001, Lambin et al. 2003). Such factors can be spatially correlated to a large extent, and distance plays a major role. Tobler's Law suggests that "everything is related to everything else, but near things are more related than distant things." (Tobler 1970 page 236) However, it is not clear how correlations in existing and potential development diminish with distance. In this study, empirical connections between parcel changes and neighborhood attributes were sought via calibration and application of discrete choice models.

As functionally distinct observational units, parcels lend themselves to disaggregate

On-Road Vehicle Technologies on Air Quality in the United States: Modeling and Analysis of a Case Study in Austin, Texas."

analysis with discrete responses for use type and subdivision. This was done here, using parcel data from the City of Austin, Texas in the years 1995 and 2000. Of course, parcels can evolve in size and shape, not just land use. The likelihood of subdivision was modeled explicitly, using a binary logit, before modeling the likelihood of land development. The act of subdivision can indicate that a parcel (or a portion of that parcel) is more likely to develop in the near term.

[3] For this reason, two models of land development were calibrated: one that applied to parcels that had subdivided in the 5-year period, and one for whole/undivided parcels. Based on these three models, year 2005 land uses were predicted, resulting in a picture of that area's land use future.

The following sections discuss related research in the land use modeling topic area, the data sets and methods used here, as well as model results, application and conclusions.

2. Literature review

Many land use/land cover change models have been developed, yet there is no clearly superior approach. This is thought to be due largely to the complexity of the land development process, and to differences in available data sets and modeling objectives (Parker et al. 2003).

The land use models reviewed here[4] are primarily focused on parcel applications, which offer more behavioral realism and enjoy significant potential in the land use

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[3] For example, of the 1.31% of vacant parcels that subdivided between 1995 and 2000, 78.3% were developed by 2000. In contrast, only 46.4% of the unsubdivided vacant parcels were developed by 2000.

[4] Lowry-type gravity models (such as Putman's ITLUP [Putman 1983, 1992, 1995]), multiregional input-output models (such as la Barra's TRANUS, Hunt's PECAS, and Kockelman's RUBMRIO [De la Barra 1989, Johnston and De la Barra 2000, Abraham and Hunt 2002, Hunt and Abraham 2003, Zhao and

modeling domain because of recent advancement in geographic information system (GIS) technologies.

Many such models are based on rules of land availability and suitability for development. Landis' (1994, 1995) first California Urban Futures model (CUF I) allocates new urban development according to real estate profitability, and is the first to use GIS to simulate large-scale metropolitan areas. Other rule-based models include Klosterman's *What if?* (Klosterman 1999, Pettit 2005) and Johnston's Uplan (Johnston and Shabazian 2003). These latter two rely on the concept of balancing supply and demand, but otherwise lack strong theoretical foundation. With the advancement of discrete choice theory, Landis' second CUF model (CUF II) (Landis and Zhang 1998a, 1998b) incorporates more land use types via a series of probabilistic equations. Adding further behavioral mechansims, Waddell's UrbanSim (Waddell 2002, Waddell et al. 2003, Waddell and Ulfarsson 2004) seeks to simulate the land-market interactions (and location choices) of households, firms, developers and public actors. However, both the rule-based models and the more microscopic UrbanSim lack the majority of neighborhood variables constructed and controlled for here.

Of course, neighborhood impacts on land use change have been controlled for in other applications. For example, Verburg et al. (2004) explored the determinants of land use change using grid-cell maps of the Netherlands. They constructed separate binomial logit models for residential, industrial/commercial, and recreational land uses. Such use of multiple models is tedious for application. Moreover, their 500m x 500m resolution is probably too

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Kockelman 2004, Kockelman et al. 2005]), and models built on urban economic bid-rent theory (such as Martinez's MUSSA and Anas's METROSIM [Martinez 1992, 1996, Anas 1994]) are all of interest. However, they are not highly related to methods applied here. Due to space constraints, these are excluded from the following discussion.

coarse to discover the underlying spatial relationships. In contrast, Irwin and Bockstael (2004) applied parcel data to detect indirect effects of land use policies on urban sprawl. However, they restricted their investigation to residential uses.

A cellular automata (CA) approach can be useful for representing relationships between a location and its immediate environment, permitting rapid simulation of large-scale cell-based systems. Clarke's CA-based SLEUTH model (of Slope, Land use, Exclusion, Urban extent, Transportation and Hill shade) has been applied to several U.S. and international urban areas (Clarke et al. 1997, Clarke and Gaydos 1998, Silva and Clarke 2002, Syphard et al. 2005). However, CA models rely on predetermined rules, and lack sound economic theory foundation to explain the development procedure (as well as statistical theory for simultaneous estimation of model parameters). Moreover, CA models operate under a grid-cell environment. Thus, a single parcel of land, which typically changes as a whole (in reality), may be divided into several grid cells and be predicted to experience different development types at once. This feature can diminish the reliability of such models.

In terms of spatial correlation, linear regression models and statistical methods for continuous data outcomes (such as population per census tract and home prices) have been analyzed in some depth (e.g., Anselin 1988, 2002, Pace et al. 1998, Kelejian and Prucha 1998, Le Sage and Pace 2004). Some work has been conducted using discrete responses. Beron and Vijverberg (2002) proposed a Monte Carlo analysis for a probit model with spatial components. However, substantial simulation processing time prohibits its applications in regional models of land use change, where both the sample size and parameter space are large. Frazier and Kockelman (2005) incorporated both spatial and temporal correlation in logistic models of land use proportions data using 300 m grid cells based on satellite images of Austin. And Wang and Kockelman (2006) essentially enhanced these models through mixed logit model.

In contrast to the above models and methods, this work emphasizes parcel-level data, examines both subdivision and land development outcomes, and relies on a variety of neighborhood attributes that are continuous in nature to better control for spatial dependencies.

3. Data description

This section describes the data used to calibrate the parcel subdivision and land development models. Many variables had to be constructed, using GIS capabilities available in ESRI's ArcMap 9.0.

3.1. Land use classification

The City of Austin's Neighborhood Planning and Zoning Department (NPZD) provided land use parcel maps for 1995 and 2000. The study area is the overlay of the two maps. It includes the City of Austin 2-mile extraterritorial jurisdiction, an approximate oval area, containing 420 square miles.

The City classifies parcels according to 15 distinct land use categories, as listed in Table 1. For ease of modeling and interpretation, these 15 were grouped into 9 types: Residential, Commercial, Office, Industrial, Civic, Undeveloped, Transportation, Water and Other. (Table 1's third column shows the groupings.) All 611 parcels labeled as unknown were checked against 1995 and 2002 orthophotos[5], and an appropriate land use code was determined.

The resulting data set suggests many types of land use transitions between 1995 and 2000, as shown in Table 2. Less than 1% of all developed parcels experienced land use change between 1995 and 2000, while 58.8% of all undeveloped parcels subdivided and/or changed use. Therefore, only parcels that were undeveloped in the year 1995 are considered in the three models developed here.

Parcels measuring less than 3,000 square feet were examined using orthophotos, in order to remove highly irregular/unusual shapes or “chips”, which were unlikely to experience development (or even truly exist as developable parcels). As with very small undeveloped parcels, all single-family parcels of less than 2000 square feet were examined using orthophotos. In order to explore the extent of neighborhood impact, a 3-mile wide buffer was created inside the study area boundary. In order that adequate neighborhood information could be obtained for all sample parcels, only those within this buffer were included in the final data set. This inner area provides a total of 12,015 parcels (that were undeveloped in 1995), as shown in Figure 1. Among these, just 157 subdivided before 2000; the other 11,858 remained whole. Tables 3 and 4 describe the fraction of parcels or land under each land use category in 2000.

3.2. Measures of topography and zoning policies

Topographic conditions have a bearing on land use changes (e.g., Silva and Clarke 2002,

[5] The 1995 orthophotos provide images with a 1m x 1 m resolution; they were obtained from the website of Texas Natural Resource Information System (TNRIS). The 2000 orthophotos have 2 ft x 2 ft resolution, and were downloaded from the Capital Area Council of Governments (CAPCOG) webpage.

Verburg et al. 2004). In particular, a highly sloped parcel is costly to develop. Land use policies also play an important role in shaping land use patterns. Zoning decisions facilitate the development of some uses while impeding others.

The U.S. Geological Survey's national elevation dataset (NED) offers the best-available elevation data for the Austin region, at an approximate 10-meter pixel resolution. Slopes were computed as the maximum change in elevation over the centroid distance between each cell and its 8 neighbors. Slopes of multiple pixels having centroids located within a single undeveloped parcel were then averaged.

Zoning data was obtained from the City of Austin's NPZD, and was grouped into residential, commercial, office and industrial uses. The zoning designations entered the land use models as indicator variables, allowing one to quantify their influence on land development.

3.3. Measures of local land use and entropy, based on parcel data

The nature and extent of each undeveloped parcel's surrounding "neighborhood" were quantified in several ways. Land use area totals and land use balance in a series of concentric neighborhoods were calculated based on the parcel-level data.

The total areas of commercial, office, industrial, civic and undeveloped uses served as explanatory variables in logit models of subdivision and land use change. In order to test the extent and sensitivity of neighborhood impacts, a variety of neighborhoods were defined, based on circular or ring geometries. The defining radii ranged from 0.5 miles to 3.0 miles, in increments of 0.5 miles. Knowing the total area (by land use type) surrounding each undeveloped parcel, a measure of local land use balance was constructed. Based on deviations in local land use percentages, relative to a “perfect” (equal-proportions) land use balance (Kockelman 1997), this explanatory variable was defined as follows:

$$Entropy = -\frac{1}{\ln(J)}\sum_{j}^{J} P_j \ln(P_j) \quad (1)$$

where J is the number of land use types under consideration and P_j is the fraction of the neighborhood that is of land use type j.[6]

Only 5 developed land uses (residential, commercial, office, industrial and civic) were included in this entropy equation, so there were no penalties for a large extent of undeveloped area. (The other neighborhood variables control for such situations.) Both the total area and the percentage of each land use across each of the six neighborhoods were calculated around every undeveloped parcel. In the logit models of subdivision and land use change, this index helps reveal the preference of land development for neighborhoods offering more balanced land uses.

Rather than simply counting all residentially used parcels for a measure of the residential “intensity” of a parcel’s neighborhood, estimates of household counts were used. The method used is described below.

3.4. Measure of local residential use intensity, based on census data

Population growth is a major driving force for urbanization and land use change (e.g., Li et al. 2003, Lambin et al. 2003). In order to account for neighborhood population effects, census-tract counts of dwelling units were allocated to residential parcels within that tract. Each single-family parcel was assigned one housing unit, while mobile home and

[6] This land use balance term ranges from 0 to 1, with 0 indicating that all neighboring developed uses are of a single type and 1 indicating that all 5 are present equally (at 20%).

multi-family parcels were combined to absorb all remaining units. Each mobile home and multi-family dwelling unit was assumed to consume the same amount of land area[7], resulting in the following average space consumption (SC_i) calculation for each of these types of dwelling units, for each census tract i:

$$SC_i = \frac{TOTAREA_{MH,i} + TOTAREA_{MF,i}}{HU_i - LLSF_i - SF_i} \quad (2)$$

where SC_i is the average space consumption per mobile home and/or multi-family dwelling unit located in census tract i, $TOTAREA_{MH,i}$ and $TOTAREA_{MF,i}$ are total (parcel-based) areas designated as mobile home and multi-family in census tract i, HU_i is the total (census-based) number of housing units in census tract i, and $LLSF_i$ and SF_i are the total (parcel-based) numbers of large lot single-family and single-family in census tract i.

The above equation was applied using year-2000 Census and parcel data sets, and Table 5 shows the statistics for average space consumption at the census tract level. Assuming that this variable did not change significantly between 1995 and 2000[8], the results were assigned to year-1995 mobile-home and multi-family parcels. Each mobile home and multi-family parcel was divided by its SC value to provide an estimate of the number of housing units located there. Households assigned to multi-family (including mobile home) were then allocated uniformly across 40 m x 40 m grid cells in those parcels, and those cells' contributions to the total were counted if they fell within the six

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[7] This assumption is due to a lack of better information on how such units actually compare, in terms of their effective land requirements. The *SC* equation could be modified rather easily to reflect any systematic discrepancies in space needs.

[8] Some housing units are located in census tracts not entirely covered by the buffered study area. The total (census-based) number of housing units could not be assumed in these cases, for use in the SC equation. Thus, in these cases, SC values were estimated as the average value of those in adjacent census tracts.

neighborhoods (of 0.5 mile increments). Single-family parcels were counted if their centroids lay within the defined neighborhood.

The following section discusses explanatory variables that recognize network access, another source of spatial autocorrelation.

3.5. Transportation network variables

Many studies have shown that transportation networks affects land use change (e.g., Silva and Clarke 2002, Frazier and Kockelman 2005). Locations enjoying greater access to transportation services are more likely to be developed.

Austin is a medium-size metropolitan area with a single, dominant central business district (CBD). For this reason, each parcel's network distance to the CBD is felt to be a reasonable access proxy. The Capital Area Metropolitan Planning Organization's (CAMPO) highway and transit networks were used to calculate this and two other explanatory access variables. The CBD was defined as a 0.39-square mile rectangular area bounded by Guadalupe Street, Red River Street, Cesar Chavez Street and East 11th Street. CBD distances were calculated from each undeveloped parcel's centroid to the edge of the CBD using Caliper's TransCAD software for shortest travel-time path under peak-hour conditions. Distances to the nearest highway were computed from parcel centroids using ArcGIS's spatial analyst function (as a Euclidean distance). Transit access was defined as the number of transit stops within a 0.5 mile radius of each undeveloped parcel's centroid.

4. Methodology and results

Standard, linear-in-unknown parameters logit models of subdivision and land use change were successively calibrated by considering all explanatory variables using a process of stepwise addition and deletion. As described above, neighborhood conditions were represented as the number of nearby homes and as the total nearby areas of other land use types (for commercial, office, industrial, civic and undeveloped uses). Commercial land uses are expected to represent shopping opportunities, while office, industrial, and civic uses represent a form of job opportunity. Residential units reflected population density; they also represent another type of opportunity, primarily communal or social in nature. Measures of local land use balance; highway, CBD and transit access; parcel slope; and parcel size and shape variables also were included.

All variables were included from the start, and then removed in a stepwise fashion, generally according to their statistical significance. Explanatory variables representing the most local (0.5-mile) neighborhood conditions were considered before examining the contributions of more distant neighborhood variables (1.0 mile and beyond). Explanatory variables offering p-values of less than 0.10 were removed in a stepwise fashion. Coefficients of different neighborhoods were restricted to be equal if they were statistically equivalent, according to a likelihood ratio test (Train, 2003). Several types of variables did not meet the test of statistical significance, but many remained. The following discusses the three models' results.

4.1. Land use subdivision model

Table 6 provides summary statistics of all explanatory variables used in the final subdivision model (where y = 1 if the undeveloped parcel subdivided between 1995 and 2000), and the results are shown in Table 7. The final model suggests that neighborhood impacts on the likelihood of parcel subdivision were limited to 1.0-mile neighbors.

Not surprisingly, parcel size has a positive impact on subdivision; the larger an undeveloped parcel, the more likely it will subdivide. However, this effect is not very practically significant, with an elasticity[9] value of just 0.0283. The ratio of parcel perimeter to parcel size has quite a negative impact, with a highly practically (and statistically) significant elasticity of -6.23. Parcel slope is estimated to exert a negative impact on subdivision likelihood, indicating that flatter parcels are more likely to subdivide and then develop into other land uses. The elasticity of parcel slope is 0.171 .The proximity of more undeveloped parcels within the 1.0-mile neighborhood dampens the likelihood of subdivision, as one would expect. The elasticity of subdivision probability with respect to this variable is a practically significant -1.30.

4.2. Land use change: unsubdivided parcels

The vast majority (98.7%) of undeveloped parcels did not subdivide between 1995 and 2000. But many (45.7%) experienced development and thus a land use change. Table 8 provides summary statistics of all explanatory variables used in Table 9's multinomial logit model results for unsubdivided parcels. The model indicates that neighborhood impacts on parcel change do not extend beyond the 3.0-mile limit used here.

The magnitudes and signs of parameters for variables like parcel size, parcel shape and slope are all as expected. (For example, smaller parcels are less likely to develop into

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[9] Elasticity is defined as $E_{ni} = \frac{\partial V_{ni}}{\partial X_{ni}} X_{ni}\left(1 - P_{ni}\right)$, where V_{ni} is the systematic utility associated with alternative i for individual n; X_{ni} is individual n's explanatory variable of interest; and P_{ni} is individual n's probability of choosing alternative i. The elasticity for each individual n's are averaged to get the computed elasticity.

residential uses. Parcels with a higher perimeter-to-area ratio are more likely to develop into residential use, which is consistent with the 2-to-1 dimensions often found on residential parcels, in contrast to the more nearly square shapes evident for commercial, office, and civic uses. Parcel slope has a negative effect on development likelihood, most likely due to higher costs of construction and parcel use.) It may seem counterintuitive that the negative transit access coefficient suggests residential development is less likely in neighborhoods better served by transit. However, transit stops are clustered in the most developed areas of the City, where land development is rare and non-residential uses are relatively common. Thus, this transit variable may be picking up many effects of centrality and commercial development, rather than noting purely access considerations.

A distance-to-CBD variable is included to reflect regional access tendencies, and the positive signs on its coefficients, specific to residential and office development, indicate that residential and office land uses are more likely to appear in undeveloped parcels near the city fringe. This is consistent with the process of sprawl, as well as Ota and Fujita's (1993) economic models for multi-unit firms located in suburban areas. The negative signs on distance to nearest highway suggest that residential, commercial and office uses are likely to emerge near highways, taking advantage of transportation access (to other businesses as well as households and offices around the region). Zoning appears to facilitate development of corresponding land uses, but does not necessarily impede other land use types.

Interestingly, the entropy measures of neighborhood land use balance are estimated to have negative impacts on residential and commercial development likelihoods, suggesting residential and commercial uses favor neighborhoods with less diverse land uses. This may be indicating that clusters and homogeneity of land use (ostensibly residential or commercial in nature) are preferred to variety, while reflecting the inertial effect of historic/existing building patterns. This coincides with empirical findings and theoretical models in the economic geography (e.g., Fujita and Thisse 1996). This clustering of like land uses is also found in the estimates of surrounding land use intensity (rather than just entropy). For example, the number of residential housing units within 1 mile is estimated to increase the likelihood of residential development. Commercial development within a 0.5-mile radius also is estimated to increase the likelihood – not just of commercial use, but also of residential and office development, indicating a clustering or agglomeration effect of such uses. This clustering effect also is found in office development, within a 1-mile neighborhood. And the presence of office uses within 1.5 miles increases the likelihood of residential development.

Some neighborhood attributes have mixed effects on land use change. For example, the presence of an undeveloped area within a 0.5-mile neighborhood is estimated to have a positive impact on residential conversion, revealing a general preference for living near undeveloped, and possibly more scenic and less polluted areas. However, undeveloped areas in a 0.5 to 1 mile ring around an undeveloped parcel do not appear to attract residential development, possibly because other, closer undeveloped parcels provide more development opportunities.

Finally, the model detects only one dispersive force among like land uses: Civic uses within a 1-mile neighborhood decrease the likelihood of other civic development. This may relate to the nature of civic uses, which seek broad distribution in order to provide more equitable access.

4.3. Land use change: subdivided parcels

For each subdivided undeveloped parcel, a proportion of its total area changed into one of the 7 basic land use types (undeveloped, residential, commercial, office, industrial, civic and other). In many cases, the proportions were 100% or 0%, depending on the land use type. But most (109 out 157 subdivided parcels) offered a mix of land uses on what was previously an undivided, undeveloped parcel. Since transportation was not a permitted use, any emergent roads and streets on such parcels were allocated to the new uses in proportion to their respective sizes. Summary statistics for all explanatory variables are given in Table 10. And Table 11 provides the model results, which suggest that neighborhood impacts were limited to a 0.5 mile radius. Of course, with just 157 parcels in this data base, statistical significance is less likely to emerge, in contrast to the over-11,000-point data base used in the earlier model of land use change (for unsubdivided parcels).

Consistent with the earlier model, the ratio of parcel perimeter to parcel size increases the likelihood of residential development, with an elasticity of 0.592 (as compared to 0.181 in the model for unsubdivided-parcel change). Average parcel slope is estimated to decrease the likelihood of commercial development, with an elasticity of -1.17 (relatively comparable to -1.08 in the model for unsubdivided-parcel change). Euclidean distance to the nearest highway is estimated to have a negative impact on the likelihood of commercial development, resulting in an elasticity of -4.41 – more than double the corresponding elasticity in the earlier model.

Residential and industrial zoning regulations are not estimated to have significant influences on any land uses, when an undeveloped parcel is facing subdivision and development. Commercial and office zoning appear to have a positive impact on such development, and commercial and industrial zoning policies do not appear to inhibit office development (which is a “lesser” use and therefore permitted under those designations).

As in the earlier model, commercial uses are attracted to other businesses, but not to homes within a 0.5-mile neighborhood. More undeveloped land within a 0.5-mile neighborhood is estimated to have a negative impact on office and “other” types of development.

This model does counter the results of the model for unsubdivided parcels in some respects. These distinctions suggest that the development process may differ for subdivided and unsubdivided parcels, to some extent validating the use of separate models. Both are useful in prediction, as discussed below.

5. Prediction

Given the large number of observations, the models of subdivision and land development have reasonably high log-likelihood ratio indices (LRIs). These are computed to be 0.38, 0.26 and 0.22 for the subdivision model, the unsubdivided parcel land use change model, and the subdividing-parcel land use change model, respectively. In order to apply the three models’ estimates, a 2005 land use pattern was predicted based on parcels that were undeveloped in the 2000 map.

Each undeveloped parcel was predicted to either subdivide or remain whole in 2005, according to the most likely probability calculated in the subdivision model. Subdivided and unsubdivided parcels were then fed into the appropriate land use models. 7490 out of the 7509 undeveloped parcels were estimated to evolve whole, and were fed into the model for unsubdivided parcels. Among these, 2252 (or 30.1%) were predicted to convert into residential use, 57 to commercial, 58 to office, 1 to industrial, 7 to civic, and 8 to other (open space, mining, and utility). 5107 (68.2%) were simulated to remain undeveloped. The other 19 were predicted to subdivide, and were fed into the land use change model for subdivided parcels. Of course, subdivision results in multiple parcels. However, the number and size of each of these were not modeled here. Instead, the calibrated land use change model focuses on the *shares* of the resulting land uses. So only a single random number was drawn for each of these subdividing parcels, and a single 2005 land use was assigned to each. Given that there are relatively few subdividing parcels (1.6% of the total), any errors associated with this approach to prediction are expected to be small. Of the 19 subdividing parcels then, 84.2% were estimated to develop: 2 as office and 14 as “other” land use types.

Figure 2 shows the models’ “most-likely” land use predictions for the year 2005 in the whole study area. Intensive development is predicted to happen in the north-west corner of the region. The upper map in Figure 3 provides a snapshot of the potential future, for a 3 mile x 3 mile area, where three major highways converge (MoPac/Loop 1, Loop 360, and US 183). Actual 2005 land use patterns were collected on site to facilitate model validation. The accuracy at the individual parcel level is not high: 8 of the 12 predicted undeveloped parcels matched their actual 2005 land uses, along with only 61 of the 134 (predicted) residential parcels, 1 of the 7 commercial parcels, 4 of the 12 office parcels, and none of the

5 “other use” parcels. However, the proposed land use model is intended to provide inputs to traffic demand models, rather than predict parcel by parcel. Thus, the accuracy of average land uses at the traffic analysis zone level is of greater interest than that at the level of individual parcels. In order to test the impacts of aggregated area size on model performance, a 1.3 mile x 1.3 mile sub-area was extracted from the snapshot area. This smaller area is bounded by two major highways (US 183 and Loop 1) and a minor connector (North Capital of Texas Highway) between them. Tables 12 and 13 compare total land use areas between model predicted and actual land uses in the 1.3 mile x 1.3 mile and 3 mile x 3 mile areas, respectively. The prediction accuracy improves noticeably as the sampling area increases. (For example, the ratio of prediction to actuality increases from 0.027 to 0.163 for undeveloped land.)

Of course, this is a single simulation applying the most likely probabilities to each undeveloped parcel. Other simulation methods will paint a somewhat different situation. The greatest uncertainty lies in what happens to parcels that subdivide. Uncertainty can be quantified as entropy, using the same equation as for land use balance, but with probability predictions (by land use type) rather than proportions of land use area (e.g., Wang and Kockelman 2006). It is in the land use change model for subdivided parcels that the average uncertainty (entropy) is greatest.

6. Conclusions

This paper investigated the influence of neighborhood conditions (including land use intensity, balance and access) on parcel development using Austin land use maps from 1995 and 2000, and comparing predictions to actual developments in 2005. The models capture a great many spatial components via the use of valuable explanatory variables, illuminating the related processes of parcel subdivision and land development.

The two land use change models are consistent in the estimated impacts of the ratio of parcel perimeter to parcel size, average parcel slope and distance to nearest highways. However, the two models differ in terms of observational units and the effects of several explanatory variables, suggesting different development mechanisms for subdivided and unsubdivided parcels. Given the stability in developed parcels, this work's focus on undeveloped parcels seems reasonable, as does the use of two distinct models of land use change, as related to subdivision outcomes.

The findings from all three models reveal the substantial influence of zoning policies and neighboring development. All suggest the presence of substantial spatial autocorrelation, which was explicitly recognized in the form of various control variables. The land use change models reveal that zoning prompts the development of corresponding land uses, but does not necessarily impede other land use types. The model for unsubdivided parcels indicates that civic land uses are not likely to cluster within 1 mile of civic land uses, though residential, commercial and office land uses shows agglomerated development pattern. Positive spatial tendencies in land development are also noted between commercial and office uses, and between industrial and residential uses within 0.5-miles of one another. The extent of neighborhood impacts appears to be generally bounded by a distance of 2 miles. Parcels beyond this distance do not offer predictive power. This may offer an empirical threshold for models of land development that seek to recognize spatial autocorrelation, either through explanatory variables or through their error terms.

When applied to undeveloped parcels in the year 2000, the three models' combined predictions suggest that model performance improves when examined in aggregate (over larger areas), as expected. A high degree of improper prediction at the individual parcel level suggests that other key factors exist, such as school quality, property tax rates, economic growth rates, and so forth. However, the models show that urbanization is coming quickly to the City of Austin (and its extraterritorial lands). These models help planners, policymakers, and communities anticipate the future – in order to better shape that future.

Land use models of parcel-level changes are a valuable direction for models of land use intensity, including built space, employment and population. Extensions to this work may provide estimates of interactions and flows, providing predictions of travel demand and network use and facilitating infrastructure and policy decisions.

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List of Tables and Figures:

Table1. Land Use Categories

Original Land Use Classification	Description	Final Classification
Large Lot Single-family	Single-family detached, two-family attached with lot size bigger than 10 acres	Residential
Single-family	Single-family detached, two-family attached	
Mobile Homes	Mobile homes	
Multi-family	Three/fourplex, apartment/condo, group quarters, retirement	
Commercial	Retail and general merchandise, apparel and accessories, furniture and home furnishings, grocery and food sales, eating and drinking, auto related, entertainment, personal services, lodgings, building services	Commercial
Office	Administrative offices, financial services (banks), medical offices, research and development	Office
Industrial	Manufacturing, warehousing, equipment sales and service, recycling and scrap, animal handling	Industrial
Civic	Semi-institutional housing, hospital, government services, educational meeting and assembly, cemetery	Civic
Mining	Resource extraction	Other
Open Space	Parks/greenbelts, golf courses, camp grounds and open spaces set aside for preservation or protection.	
Utilities	Utility services	
Undeveloped/Rural	Rural uses, vacant land, land under construction	Undeveloped
Water	Water	Water
Transportation	Railroad facilities, transportation terminal, aviation facilities, marina parking facilities	Transportation
Unknown	Unknown	

Source: Land Use Survey Project Description, City of Austin

Table 2. Land Use Transitions between 1995 and 2000 (parcel-level changes)

		2000								
		Residential	Commercial	Office	Industrial	Mining	Civic	Open Space	Utilities	Undeveloped
1995	Residential	156085 (94.1%)	16 (0.0859%)	10 (0.0406%)	14 (0.641%)	1 (0.0749%)	30 (0.232%)	6 (0.260%)	1 (0.000416%)	273 (4.58%)
	Commercial	25 (0.617%)	4647 (97.9%)	4 (0.174%)	8 (0.351%)		5 (0.118%)	2 (0.140%)	1 (0.017%)	14 (0.723%)
	Office	2 (0.0297%)	8 (0.164%)	1928 (99.4%)	3 (0.339%)					2 (0.0531%)
	Industrial	33 (0.875%)	15 (0.314%)	1 (0.0281%)	2201 (98.3%)		1 (0.112%)	1 (0.0352%)		25 (0.334%)
	Mining	0				64 (99.99%)				1 (0.00676%)
	Civic	29 (0.340%)	3 (0.410%)		1 (0.007%)		1318 (99.2%)			2 (0.0291%)
	Open Space	6 (0.0560%)		1 (0.0134%)	1 (0.0253%)		1 (0.130%)	1225 (99.7%)		
	Utilities								184 (99.98%)	1 (0.0185%)
	Undeveloped	21329 (14.4%)	438 (1.16%)	180 (0.883%)	264 (1.06%)	49 (1.02%)	167 (1.07%)	907 (11.8%)	38 (0.063%)	16726 (68.5%)

Note: Upper numbers are number of parcels in each use type, while lower numbers in parentheses are percentage of land in each use type.

Figure 1. Map of Austin's Undeveloped Parcels in 1995

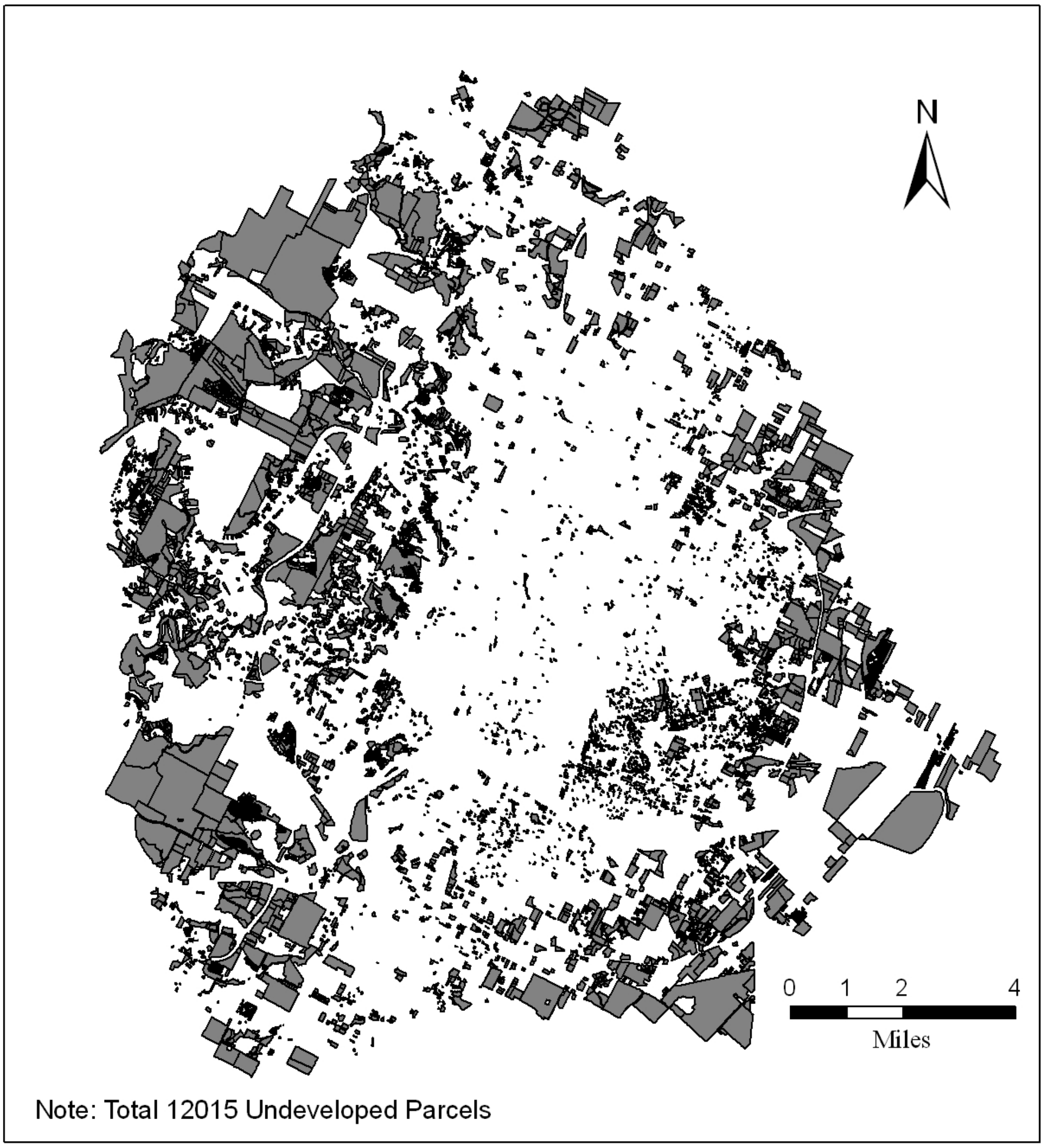


Table 3. Parcel Data Set Description: 2000 Unsubdivided Parcels

2000 Status		Number of Observations	Percentage (%)
Undeveloped		6362	53.65
Residential	Large Lot Single-family	30	39.54
	Single Family	4556	
	Mobile Home	24	
	Multi-family	79	
Commercial		216	1.82
Office		113	0.95
Industrial		113	0.95
Civic		89	
Other	Open Space	259	2.33
	Mining	4	
	Utility	13	
Total		11858	100

Note: All parcels described in this table were undeveloped in 1995.

Table 4. Parcel Data Set Description: 2000 Subdivided Parcels

2000 Status	Number of Observations	Minimum	Maximum	Mean	SD
Undeveloped Fraction	157	0.000	0.998	0.318	0.347
Residential Fraction	157	0.000	1.000	0.296	0.374
Commercial Fraction	157	0.000	1.000	0.126	0.297
Office Fraction	157	0.000	1.000	0.0695	0.230
Industrial Fraction	157	0.000	1.000	0.0418	0.174
Civic Fraction	157	0.000	1.000	0.0241	0.123
Other Fraction	157	0.000	1.000	0.124	0.272

Note: All parcels described in this table were undeveloped in 1995.

Table 5. Average Space Consumption Description

Number of Census Tracts	Minimum	Maximum	Mean	SD
172	345	67217	4811	8015

Table 6. Description of Dependent Variables in Final Subdivision Model

Variable	Description	Minimum	Maximum	Mean	SD
Size	Parcel size (mile^2)	0.0000636	1.47	0.00393	0.0278
Ratio	Perimeter/area (ft/SF)	0.000685	0.435	0.0370	0.0179
Slope	Average parcel slope (%)	0	23.1	2.67	2.60
Undev1.0	Total area of undeveloped use within 1.0 mile (mile^2)	0.0165	3.04	0.912	0.540

Table 7. Results of Parcel Subdivision Model

Explanatory Variables	Coefficient	t-statistics
Constants	0.230	0.86
Size	9.98	5.87
Ratio (of perimeter to area)	-168.8	-12.0
Slope	-0.0650	-1.76
Undev1.0	-1.44	-6.94
Log Likelihoods		
Market Shares	-836.983	
Convergence	-518.860	
LRI	0.38	
Number of Observations	12015	

Note: Unsubdivided parcel is the base for all variables.

Table 8. Description of Dependent Variables in Final Land Use Change Model for Unsubdivided Parcels

Variable	Description	Minimum	Maximum	Mean	SD
Size	Parcel size ($mile^2$)	0.0000636	0.939	0.00287	0.0153
Ratio	Perimeter/area (ft/SF)	0.000960	0.435	0.0374	0.0177
Slope	Average parcel slope (%)	0	23.1	2.67	2.60
DistCBD	Network distance to CBD under peak-hour conditions (miles)	0.00416	21.7	7.18	4.37
Transit Access	Number of transit stops within 0.5 mile of the parcel centroid	0	1828	35.6	72.8
DistHWY	Euclidean distance to nearest highway (miles)	0	1.21	0.212	0.227
ResideZone	Residential use zone	0	1	0.584	0.493
CommZone	Commercial use zone	0	1	0.0926	0.290
OfficeZone	Office use zone	0	1	0.0210	0.143
IndusZone	Industrial use zone	0	1	0.0315	0.175
Resid1.0	Total number of housing units within 1.0 mile of the parcel centroid	4	13438	3033	2499
Resid1.5	Total number of housing units within 1.5 miles of the parcel centroid	24	21744	6618	5159
Resid2.0	Total number of housing units within 2.0 miles of the parcel centroid	514	32862	11952	8790
Comm0.5	Total area of commercial use within 0.5 mile of the parcel centroid ($mile^2$)	0.00	0.286	0.0193	0.0301
Comm1.0	Total area of commercial use within 1.0 mile of the parcel centroid ($mile^2$)	0.00	0.694	0.0796	0.103
Comm1.5	Total area of commercial use within 1.5 miles of the parcel centroid ($mile^2$)	0.00	1.16	0.191	0.203
Office0.5	Total area of office use within 0.5 mile of the parcel centroid ($mile^2$)	0.00	0.279	0.0127	0.0262
Office0.5-1.0	Total area of office use within 0.5 to 1.0 mile of the parcel centroid ($mile^2$)	0.00	0.436	0.0551	0.0830
Office1.0	Total area of office use within 1.0 to 1.5 miles of the parcel centroid ($mile^2$)	0.00	0.369	0.0424	0.0638
Office1.0-1.5	Total area of office use within 1.0 to 1.5 miles of the parcel centroid ($mile^2$)	0.00	0.695	0.114	0.133
Indus0.5	Total area of industrial land use within 0.5 mile of the parcel centroid ($mile^2$)	0.00	0.468	0.0278	0.0542
Indus1.0	Total area of industrial land use within 1.0 mile of the parcel centroid ($mile^2$)	0.00	1.07	0.118	0.171
Civic0.5	Total area of commercial use within	0.00	0.460	0.0309	0.0441

	0.5 mile of the parcel centroid ($mile^2$)				
Civic1.0	Total area of commercial use within 1.0 mile of the parcel centroid ($mile^2$)	0.00	1.11	0.144	0.156
Undev0.5	Total area of undeveloped use within 0.5 mile of the parcel centroid ($mile^2$)	0.00195	0.771	0.239	0.153
Undev0.5-1.0	Total area of undeveloped use within 0.5 to 1.0 mile of the parcel centroid ($mile^2$)	0.00856	2.27	0.673	0.406
Undev1.0	Total area of undeveloped use within 1.0 mile of the parcel centroid ($mile^2$)	0.0165	3.04	0.912	0.540
Undev1.5	Total area of undeveloped use within 1.5 mile of the parcel centroid ($mile^2$)	0.0519	5.85	2.03	1.10
Entropy0.5	Land use balance within 0.5 mile of the parcel centroid	0.00	0.798	0.375	0.159
Entropy0.5-1.0	Land use balance within 0.5 to 1.0 mile of the parcel centroid	0.0347	0.805	0.418	0.156
Entropy1.0-1.5	Land use balance within 1.0 to1.5 miles of the parcel centroid	0.141	0.780	0.441	0.135

Table 9. Results of Land Use Change Model for Unsubdivided Parcels

Explanatory Variables	Coefficient	t-statistics
Constants		
Residential	3.30	10.79
Commercial	-0.0966	-0.16
Office	0.289	0.42
Industrial	-7.34	-9.75
Civic	-3.57	-6.94
Other	4.54	6.12
Size		
Residential	-29.8	-6.78
Ratio (of perimeter to area)		
Residential	8.23	4.66
Commercial	-20.3	-4.07
Office	-52.3	-5.96
Civic	-44.8	-6.43
Other	-9.91	-2.35
Slope		
Residential	-0.100	-10.00
Commercial	-0.406	-5.28
Office	-0.359	-4.80

Industrial	-0.628	-4.15
Civic	-0.364	-4.20
Transit Access		
Residential	-0.00922	-8.60
DistCBD		
Residential	0.0487	5.40
Office	0.135	3.68
Other	0.0567	2.58
DistHWY		
Residential	-0.271	-1.88
Commercial	-9.36	-5.49
Office	-4.41	-3.33
ResideZone		
Residential	0.832	13.46
Commercial	-2.78	-5.79
Office	-1.34	-3.31
Industrial	-2.14	-3.47
CommZone		
Residential	-1.58	-7.89
Commercial	1.07	5.57
Industrial	1.31	3.31
Other	-1.07	-2.99
OfficeZone		
Residential	-1.87	-5.52
Office	2.27	8.64
Civic	1.00	2.41
IndusZone		
Residential	-3.78	-5.17
Office	1.08	3.11
Industrial	2.28	5.61
Reside1.0		
Residential	0.0000497	2.30
Commercial	-0.000138	-2.93
Office	-0.000209	-2.88
Reside1.5		
Other	0.0000763	3.06
Reside2.0		
Industrial	0.0000484	2.04
Comm0.5		
Commercial	16.9	7.90
Industrial	-13.5	-2.96
Other	18.2	5.91
Comm0.5-1.0		
Other	3.72	2.54

Comm1.0		
Residential	1.20	2.36
Comm1.0-1.5		
Residential	2.49	6.34
Comm1.5-2.0		
Residential	0.651	2.17
Comm1.5		
Office	1.22	1.86
Office0.5		
Residential	14.4	9.38
Commercial	8.48	3.92
Industrial	-10.6	-2.56
Civic	-17.0	-3.25
Other	17.2	6.82
Office0.5-1.0		
Industrial	4.05	2.22
Civic	11.2	8.42
Other	6.19	3.65
Office0.5-1.5		
Residential	3.06	8.63
Office1.5-2.0		
Residential	-0.652	-1.70
Office1.0		
Office	3.79	3.80
Indus0.5		
Office	-8.29	-3.76
Civic	-9.72	-3.54
Indus1.0		
Residential	0.743	2.35
Commercial	1.15	2.93
Other	2.75	3.74
Indus1.0-1.5		
Residential	-0.546	-2.20
Civic0.5		
Industrial	-13.4	-3.91
Civic1.0		
Residential	1.49	5.03
Office	-4.76	-3.65
Civic	-1.93	-1.93
Other	5.19	10.56
Undev0.5		
Residential	0.909	3.22
Commercial	-1.98	-2.05
Undev0.5-1.0		

Residential	-0.741	-6.06
Undev1.0		
Other	-1.24	-4.80
Undev1.0-1.5		
Other	-0.430	-1.92
Undev1.5		
Office	-0.899	-4.67
Entropy0.5		
Residential	-4.65	-12.36
Commercial	-2.77	-2.89
Industrial	7.51	4.83
Civic	3.41	2.74
Other	-8.32	-8.54
Entropy0.5-1.0		
Residential	-5.18	-9.26
Other	-10.3	-7.03
Entropy1.0-1.5		
Residential	-2.77	-5.69
Other	-3.62	-3.15
Log Likelihoods		
Market Shares	-11707.842	
Convergence	-8615.3496	
LRI	0.26	
Number of Observations	11858	

Note: Undeveloped land use type is the base for all variables.

Table 10. Description of Dependent Variables in Final Land Use Change Model for Subdivided Parcels

Variable	Description	Minimum	Maximum	Mean	SD
Ratio	Perimeter/area (ft/SF)	0.000685	0.0443	0.00915	0.00802
Slope	Average slope (%)	0.188	9.93	2.65	2.34
DistHWY	Euclidean distance to nearest highways (mile)	0.00758	1.22	0.180	0.203
ResideZone	Residential use zone	0	1	0.287	0.454
CommZone	Commercial use zone	0	1	0.166	0.373
OfficeZone	Office use zone	0	1	0.0764	0.267
IndusZone	Industrial use zone	0	1	0.121	0.327
Resid0.5	Total number of housing units within 0.5 mile of the parcel centroid	0	5118	805	917
Comm0.5	Total area of commercial use within 0.5 mile of the parcel centroid ($mile^2$)	0.00	0.179	0.0253	0.0347
Indus0.5	Total area of industrial use within 0.5 mile of the parcel centroid ($mile^2$)	0.00	0.359	0.0462	0.0818
Entropy0.5	Land use balance within 0.5 mile of the parcel centroid	0.00	0.734	0.388	0.174

Table 11. Results of Land Use Change Model for Subdivided Parcels

Explanatory Variables	Coefficient	t-statistics
Constants		
Residential	-0.831	-2.59
Commercial	1.11	1.43
Office	-1.57	-1.18
Industrial	-4.12	-3.13
Civic	-2.58	-4.84
Other	0.572	0.75
Ratio (of perimeter to area)		
Residential	106.2	4.08
Slope		
Commercial	-0.463	-2.04
DistHWY		
Commercial	-25.3	-2.53
CommZone		
Commercial	2.70	3.71
Office	3.52	2.57

OfficeZone Office	 3.99	 2.85
IndusZone Office	 4.25	 3.14
Resid0.5 Commercial Other	 -0.000844 -0.00112	 -2.04 -1.87
Comm0.5 Commercial Office	 19.4 -30.0	 2.00 -1.69
Industrial0.5 Residential	 -7.94	 -2.04
Undev0.5 Office Other	 -8.11 -2.92	 -2.15 -1.69
Entropy0.5 Industrial	 5.00	 1.91
Log Likelihoods Market Shares Convergence LRI	 -259.521 -202.053 0.22	
Number of Observations	157	

Note: Undeveloped land use type is the base for all variables.

Table 12. Model Performance in a 1.3 mile x 1.3 mile area

Land Use	Prediction (acres)	Actuality (acres)	Ratio of Prediction to Actuality
Undeveloped	3.52	128.3	0.0274
Residential	3.84	0.00	--
Commercial	34.8	29.1	1.20
Office	44.0	0.00	--
Industrial	0.00	0.00	1.00
Civic	0.00	0.00	1.00
Other	71.2	0.00	--

Note: Values do not sum to 1.69 square miles (1081.6 acres) since models apply only to parcels that were undeveloped in 2000 (comprising 157.3 acres).

Table 13. Model Performance in a 3 mile x 3 mile area

Land Use	Prediction (acres)	Actuality (acres)	Ratio of Prediction to Actuality
Undeveloped	53.3	327.7	0.163
Residential	221.2	70.1	3.16
Commercial	41.8	32.3	1.30
Office	126.1	30.1	4.19
Industrial	0.00	0.00	1.00
Civic	0.00	0.00	1.00
Other	71.2	53.4	1.33

Note: Values do not sum to 9 square miles (5760 acres) since models apply only to parcels that were undeveloped in 2000 (comprising 513.6 acres).

Figure 2. Predicted 2005 Land Uses for the City of Austin

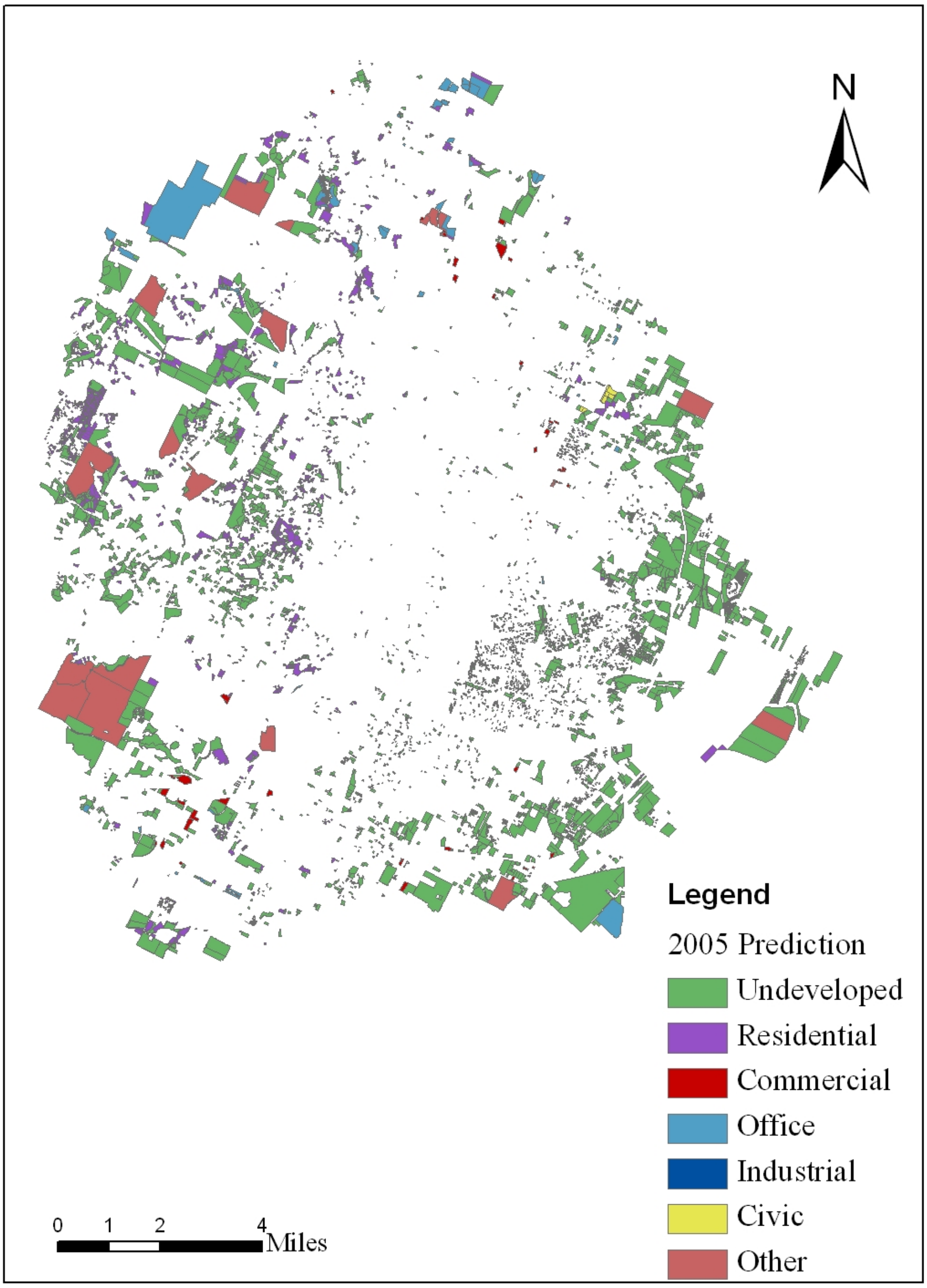
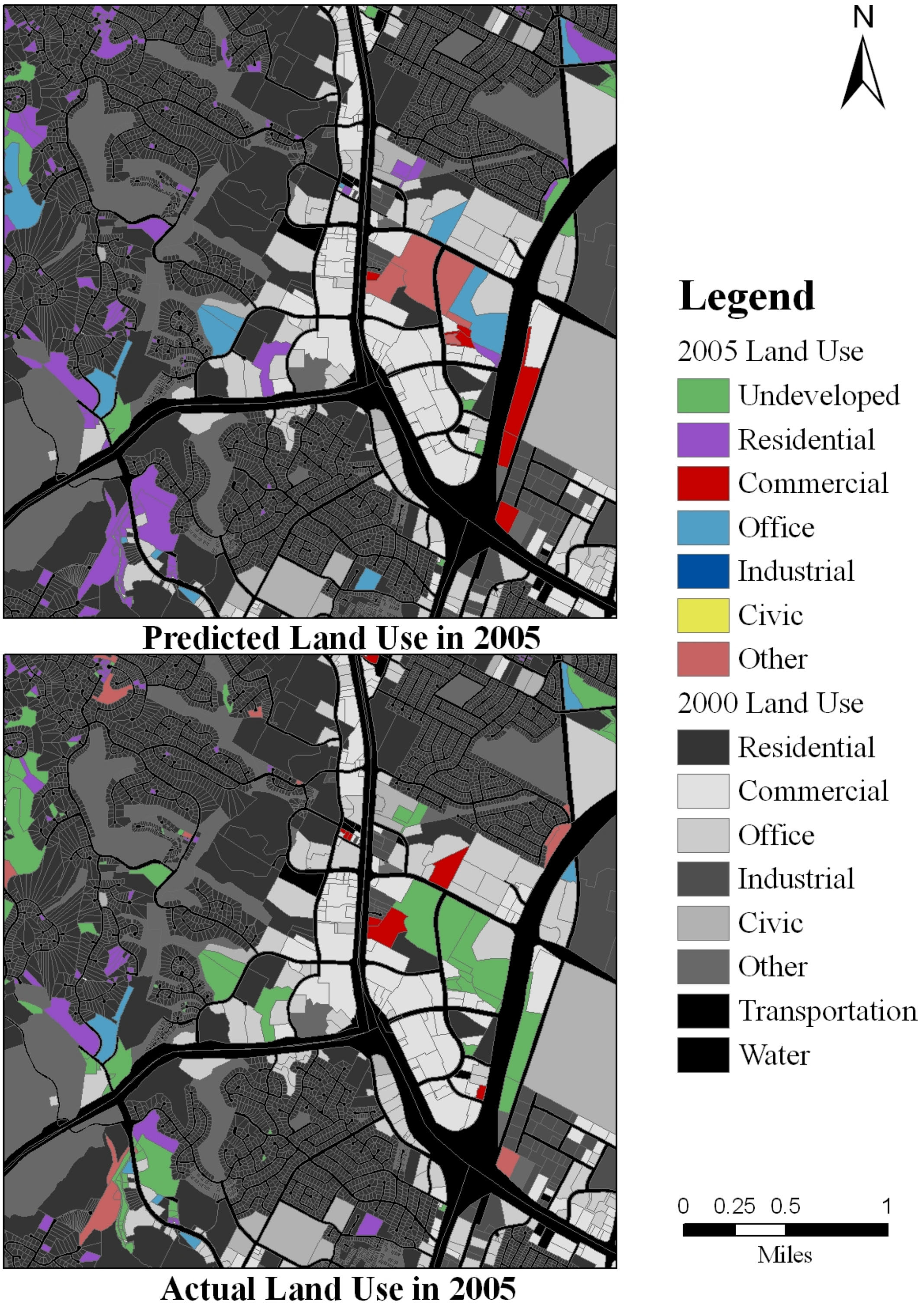


Figure 3. Predicted and Actual 2005 Land Uses for North Austin



Notes:

1. The images represent areas of 3 miles by 3 miles
2. The east-west roadway is Loop 360, the north-east roadway is US 183, and the south-east roadway is Loop 1