A Century of Land-Use Change in Metropolitan Phoenix

by

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ABSTRACT

The Phoenix, Arizona metropolitan area has sustained one of the United States' fastest growth rates for nearly a century. Supported by a mild climate and cheap, available land, the magnitude of regional land development contrasts with heady concerns over energy use, environmental sensitivity, and land fragmentation. This dissertation uses four empirical research studies to investigate the historic, geographic microfoundations of the region's oft-maligned urban morphology and the drivers of land development behind it. First, urban land use patterns are linked to historical development processes by adapting a variety of spatial measures commonly used in land cover studies. The timing of development – particularly the global financial crisis of the late 2000s, and the impact of varying market forces is examined using econometric analyses of land development drivers. This pluralistic approach emphasizes the importance of local geographic knowledge and history to empirical study of urban social science while stressing the importance of temporal effects. Evidence is found that while recent asset market changes impact local land development outcomes, preferences for place may be changing too. Even still, present-day neighborhoods are heavily conditioned by the market and institutional conditions of the historical period during which they developed, while the hegemony of low-cost housing on the urban fringe remains.

DEDICATION

To my family.

ACKNOWLEDGMENTS

First and foremost, I am heavily indebted to my co-authors for their part in the numerous projects this dissertation involved. Without the intellect and hard work of Abigail York, Joseph Tuccillo, John Connors, Chris Galletti, Yun Ouyang, and Lauren Gentile, the published works that emerged from this dissertation – and, of course, the dissertation itself – would not have been possible. I would also like to thank my supervisory committee of Bréandan Ó hUallacháin, Abigail York, and Aaron Golub without whose mentorship and patience with my stubbornness I would never have made it here. I was fortunate enough to have the assistance of a great number of others from Arizona State University's School of Geographical Sciences and Urban Planning including Sergio Rey, Elizabeth Mack, Xioxiao Li, B.L. Turner II, Mike Kuby, Scott Kelley, Joanna Merson, and Jesse Sayles; those from other ASU units including David White, Ray Quay, Mary Whelan, Sally Wittlinger, Skaidra Smith-Hesters; and those from outside the university including Sandy Dall'erba, Richard Shearmur, and number of anonymous peer reviewers; and others who I'm forgetting. Finally, I received financial and institutional support from a number of organizations and funding sources including of course the School, Central Arizona-Phoenix Long-Terms Ecological Research (NSF Grant #BCS-1026865), the LTER network office, ASU's Decision Center for a Desert City, and the Risk, Perception, Institutions, and Water Conservation in Agriculture project (NOAA Grant #NA11OAR4310123).

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PREFACE

I am not a native of Phoenix or of Arizona. I arrived here through one of the most notable migratory pipelines between city pairs in the United States: Chicago to Phoenix. Starting with wealthy entrepreneurs (the Wrigleys) and famous architects (Frank Lloyd Wright) and continuing with less renowned sun-seekers, retirees and fans of Spring Training baseball, this relocation is laden with Americana: the allure of the West and the frontier, affordable homes, automobiles, and freedom from the crime, grime, and taxes back east.

I have written on Chicago as well, an article in press at the *Journal of Planning Education and Research* about a local development tool called tax increment financing. Both cities could be described as pro-development despite their different political landscapes. While in 2011 Arizona was the second state to designate an official state firearm, it took a 2012 federal court order to make Illinois the 50th state in the nation to allow residents to carry concealed weapons in public. By 1915 Phoenix had ridded itself of geographically-bounded city wards while ward bosses remain some of the most powerful politicians in Chicago. Both, though, were built by boosters like Marshall Field and the Goldwaters.

In Arizona, buttes and sunsets substitute for skyscrapers and lakefront. It may not be as readily apparent in a city lacking iconic architecture, visually-distinct and historically-embedded neighborhoods, and just one daily transatlantic nonstop, but the Phoenix area is not, as some would have it, a “geography of nowhere.” It simply reflects a shorter and more compressed development history resulting in less differentiation in building stock, infrastructure, transportation type, and neighborhoods.

While knowledge of a place is a requisite of urban research, my interest and skill lie in empirical, data-driven research on city development. As a child of two Chicago architects and a one-time property tax professional in that city, it was issues of development finance and urban sprawl in Chicago that first piqued my interest in urbanism and motivated me to seek this PhD. Comparing the urban morphology of the two cities is the first thing I did, though it's harder to make your case using data than it is to point at the lack of skyscrapers and commuter rail. Differences in data structure, municipal and political fragmentation, and the power of large apparent differences complicates between-city comparison of within-city pattern. This dissertation repeatedly demonstrates that decisions on what to do with urban data are heavily conditioned by regional peculiarities. Also, big differences dominate nuanced ones: empirical results like average distance to transit, the impact of zoned density, or land cover diversity can seem inconsequential if one city has double the population, is in a different region of the country, or if one is New York and the other just isn't.

I hope that some progress can be made by looking at replicable approaches such as econometric modeling or what I call "historic, geographic microfoundations," testing them in one area with the benefit of local knowledge and keeping an eye toward future comparative work. As so-called "big" data is increasingly sought by local governments in order to improve policy and investment, they'll need the local knowledge to understand how to make it useful for their region and also the ability to look at how ideas that originated outside their borders might be adapted for their own use.

CHAPTER 1

INTRODUCTION

1.1 Urban Arizona

The urban morphology of the Phoenix, Arizona metropolitan area is subject to a lot of heavy-handed critique. It continually appears in the academic literature as a cautionary example of what's wrong with urbanism: a dismal early record of racial inequality (Bolin, Grineski and Collins 2005), a lack of place and identity (Gober 2006), degraded perceptions of quality of life (Guhathakurta and Stimson 2007), energy use, urban sprawl, and environmental degradation (Ross 2011). Florida (2009) goes as far as to describe Phoenix as a "giant Ponzi scheme," with speculative real estate development building on an economic base that is mainly comprised of – more speculative real estate development. Some of these critiques are reflective of the emergence of the American Sunbelt as an urban regime that is fast-growing, entrepreneurial in nature, and without a clear *raison d'être* but faces increasing challenges over climate, air pollution, and traffic congestion (see, e.g., Judd and Swanstrom 2008). Other critiques such as those over water, the urban heat island effect, and municipal politics are more unique to metropolitan Phoenix.

1.2 Research Questions

This dissertation investigates the historic, geographic microfoundations of Phoenix's (oft-maligned) urban morphology and the drivers of land development behind it. Four individual analyses are conducted to investigate this overarching question in more detail:

1. How did land use heterogeneity and complementarity develop in historic Phoenix?
2. What does fragmentation – as it is used in discussions of urban sprawl – actually mean; how does it vary in Phoenix based on when sub-metropolitan regions were developed?
3. How did the global financial crisis of the late 2000s shift the locus of new single-family home construction in Phoenix?
4. How is the urbanization of agricultural land in the Phoenix metropolitan area dependent on not only on locational and institutional characteristics, but also varying market conditions?

1.3 Methods and Conceptual Framework

This dissertation uses quantitative geographic and statistical methods to understand land-use change in the Phoenix, Arizona metropolitan area while advancing the use and application of these methods. Following Irwin and Geoghegan (2001) and Irwin (2010), land change research conducted at the scale of an individual land parcel directly links the observation unit with the decision-maker. Since urban land parcels represent actual land ownership boundaries, observing a particular pattern of land parcels connects the researcher to the processes behind their development. In landscape ecology, for example, a spatial pattern such as fractal dimension might yield a meaningful conclusion about an environmental process – species richness, for example. Similarly, a city-wide pattern of parcels may give insight into the behavior of people and their impact on the spaces they inhabit. Generally speaking, geographic pattern strongly informs the social purpose of a built area (Talen 2011). While a structural economic approach could model each landowner's utility function in order to identify development drivers, this approach runs the risk of losing the explicit connection between model observations and specific units of land within the urban environment since characteristics of individual owners are likely unavailable or obscured to protect privacy. Performing econometric analysis at the scale of the data-generating process (i.e., the parcel-level or the best available approximation) can identify key parameters undergirding a landowner's decisions especially in the short-term.

Chapters 2 and 3 of this dissertation deal with historic, geographic microfoundations of urban development. They are concerned with understanding how past trajectories yield current landscapes both explicitly by analyzing historical land use data, and implicitly by considering present-day urban morphology based on when neighborhoods were built. Whole-city spatial and space-time measures are used to understand a variety of components of urban land-use change. Chapter 2 investigates the relationship between four discrete land use categories to each other, following Kivell's (1993) observation that decline in one land use type (urban industry, in his example) can lead to altered patterns in other sectors, namely an undesired interspersion of vacant, residential, and remnant industrial land. Chapter 3 investigates the meaning of fragmentation as it is used in debates over urban sprawl (Siedentop and Fina 2010). The path-dependent nature of urban land is emphasized (Arthur 1988) whereby historic data analysis can help to understand present-day conditions and present-day data can be used to understand historic development trajectories. Metrics themselves vary; Seto and Fragkias (2005) call for a diverse set of quantitative measurements to describe various facets of urban growth. Statistics in this dissertation are necessarily tailored for specific purposes. Chapter 2 uses join-count tests to understand changing spatial relationships between land use categories and spatial transition matrices to infer the probability of certain types of change such as persistence or homogenization probability. A suite of methods called FRAGSTATS (McGarigal and Marks 1994) provides a wealth of information about land cover patterns in Chapter 3.

Chapters 4 and 5 examine land-use change processes using a binary outcome measure: whether land is developed or remains undeveloped. Using econometric methodology, multivariate logistic regression and survival analysis techniques are used to relate the instance of development to particular drivers including intraurban location, zoning and institutions, neighborhood composition, demographics, and market conditions. Chapter 4 investigates the contribution of these factors to the likelihood of single-family residential development directly before and after the global financial crisis of the late 2000s. Chapter 5 investigates the contribution of these factors to the likelihood that agricultural land becomes developed into residential use from 1992 until 2014. Preferences for neighbors, demographic shifts, the effectiveness of zoning regulations, the impact of infrastructure investment, and the impact of global financial markets on whether parcels develop is investigated. While Chapter 4 is geared toward specific shifts related to the global financial crisis including demography and neighborhoods, Chapter 5 integrates an explicitly temporal modeling technique in order to strengthen statistical identification.

Using multiple methods in this manner follows the bricolage approach suggested by Sampson (2013), who argues that a single study or dependent variable isn’t sufficient to capture all the aspects of neighborhood change in a city. Instead, a contextualist approach is proposed using a combination of several outcome measures. This dissertation's methodological approach demonstrates techniques used for within-city analysis while emphasizing that the choices made in how to understand data are heavily conditioned by local context. These include a region's development history, its physical landscape, and the institutions that demarcate land as well as keep records of its use.

A component of these necessary choices, as illustrated by this dissertation, is the question of how to define a city. Chapter 2's historical focus restricts analysis to a small area in Phoenix's downtown core that was inhabited a century ago. While limited in spatial extent, the original downtown core is emblematic of many of the broader concerns about land-use change in the region. Chapters 3 and 4 use present-day boundaries of the municipality of Phoenix. Phoenix is in fact the largest state capital in the US; in 2010 its population of 1.45 million represented about 1/3 of the metropolitan area's residents (US Census 2010). Since the bulk of the region's growth occurred during the time of the private automobile and new land was continually annexed, the city of Phoenix's density gradient roughly mirrors that of the whole metropolitan area and includes a historic core alongside suburban-style single-family homes, periurban areas, and undeveloped natural land. In chapter 5 the analysis moves to the entire metropolitan region which is almost fully bounded by Maricopa County.

1.4 Dissertation Outline

This dissertation relies on a compilation of four individual research papers on land-use change in the Phoenix, Arizona metropolitan region. Chapter 1 is based on a paper published with Abigail York, Joseph Tuccillo, Yun Oyuang, and Lauren Gentile in *Landscape and Urban Planning* (2014). Chapter 2 is based on a paper published with

John Connors and Christopher Galletti in *Applied Geography* (2014). Chapter 3 is based on a paper published with Abigail York, Joseph Tuccillo, Yun Ouyang, and Lauren Gentile in *Urban Geography* (2014). Chapter 4 is based on a manuscript prepared with Abigail York. In all cases, Kane is first author.

1.5 Summary

Understanding the spatial outcomes of driving forces of change in cities – namely the aggregated location decisions of firms and households – can help municipal and national level planners. On the local level, a better understanding of locational preferences helps to understand the response to municipal land use institutions such as zoning or development impact fees. While this dissertation only studies one metropolitan area, Phoenix is emblematic of the American Sunbelt and other fast-growing regions that are increasing in prominence and population worldwide. In particular, the region's fragile desert ecosystem, extreme temperatures, and heavily managed water and energy landscape make it an excellent example for other cities concerned about sustainability, sprawl, energy use, water availability, and climate.

Furthermore, empirical study of urban land-use change can provide verification or reflection on commonly-held historical narratives or qualitative contentions about city growth. Concerns over environmental justice are also prominent in the region (York et al. 2014, Grineski, Bolin and Boone 2007), which has a historical legacy of marginalized and spatially-concentrated populations that are disproportionately exposed to environmental hazards. New Urbanists and proponents of compact growth often emphasize the benefits of older cities in terms of walkability and land use complementarity (Talen 2005, Jacobs 1961, Duany, Speck and Lydon 2010). The ideas of compact growth can be sharpened by empirical analysis of historic cities, comparing neighborhoods based on development timing, investigating the impact of complementarity on development, or investigating the relationship between intraurban location and transportation cost. Further, such analyses can be used to gauge whether policies geared toward compact growth goals are working.

A final focus of this dissertation is achieving a spatially-explicit understanding of cities over time. Land development represents the interplay between local demand for productive places and the global market for investment capital. Developments are not only durable and immobile, they also shape the experiences and fortunes of the people who live and work there. The global financial crisis demonstrated a reciprocal effect whereby broad distribution of local mortgage debt precipitated a crisis in the global asset market, which then impacted neighborhoods in the form of foreclosures and stalled growth. Conditions in global markets have wide-ranging impacts on place. Meanwhile, and not entirely separately, preferences for place evolve over time. This dissertation investigates these topics and the imprint they leave on urban form.

CHAPTER 2

A SPATIO-TEMPORAL VIEW OF HISTORIC GROWTH

2.1 Introduction

The historical morphology of cities is often described via narratives with rich detail and thorough treatment of the peculiarities of each example. But there are also strong quantitative traditions that characterize urban growth and form, such as Burgess' concentric zone model that defined the Chicago School of urbanism (Park et al. 1925), Adams' model of urban transportation technologies (Adams 1970), and Batty's cellular automata growth models (Batty 2005). Quantitative approaches enable tests of widely held narrative contentions about urban landscapes. More specifically, parcel-level quantitative approaches connect individual land use decisions to the observed pattern of urban and urbanizing landscapes, strengthening our understanding of the underlying causal processes of land-use change (Irwin, Bell and Geoghegan 2003, Carrion-Flores and Irwin 2004, Newburn and Berck 2006, Vaughan et al. 2005).

Lax annexation laws, ample land, and a post-World War II construction boom fueled a unique Sunbelt morphology in Phoenix, Arizona (Gober 2006). This morphology is characterized by sprawling, automobile-dependent suburban expansion and speculative housing markets, contrasting with earlier eastern urban forms, which typically followed Burgess' or Adams' growth patterns around a downtown core. Phoenix represents a 20th century form of American urbanism described as rapid decentralized suburban growth (Luckingham 1989), often at the expense of urban planning and environmental justice issues (Bolin et al. 2005). It is often considered part of a new, Sunbelt urban regime that is fast-growing and entrepreneurial in nature, but faces emerging challenges such as climate, air pollution, and traffic congestion. The causal processes of change that comprise this urban regime can inform development in regions with similar growth trajectories as Phoenix (Guhathakurta and Stimson 2007, Keys, Wentz and Redman 2007). The city's central business district (CBD), the original point of modern settlement in the Phoenix Valley, fell into decline following World War II (Figure 2.1). The CBD's pattern of decline and change can be seen as an indicator of structural economic and land-use changes in the broader region. Most historical narratives of downtown decline emphasize the role of retail exodus as part of a larger structural shift and, in doing so, provide little understanding of how structural changes are manifested in land-use changes and aggregate to create urban form. Similarly, the decline of the central core saw the emergence and intensification of environmental justice issues with the siting of undesirable properties near poor, minority residential neighborhoods– an action that was exacerbated by ineffective zoning and disinvestment (Bolin et al. 2005, Talen 2012).

The objective of this paper is to use parcel-level land use data from Phoenix to link drivers of change from historical narratives to changes in urban morphology during the city's rapid period of expansion. While downtown decay, suburban-style land use homogenization, and the land use incompatibility that gives rise to environmental justice concerns have been studied (Talen 2012, Bolin et al. 2005, Gober 2006), they have not empirically considered parcel-level land use decision making – an important step in linking social and economic forces to land-use change. We seek to understand this link by addressing three questions: (1) what landscape results from the changing composition of the downtown that accompanied postwar suburban dominance, (2) to what extent is land use homogenization or incompatibility observable, and (3) how do nuisances and hazards become distributed as the city changes? In order to do so we draw on quantitative traditions in urban growth modeling, ecological modeling, and spatial analysis. First, we digitize and analyze Sanborn Fire Insurance Maps from 1915, 1949, and 1963 to characterize land use in the CBD. Second, we use simple parcel counts and transition matrices to measure the quantity of parcels in four broad land use categories and their propensity toward certain types of change. Third, we sharpen our understanding of transition types by measuring what Pontius, Shusas and McEachern (2004) call allocation disagreement. Fourth, we explicitly model interactions between parcels and their neighborhoods using join-count tests to determine how the changing quantity or allocation of parcels changes their arrangement in space. Finally, we adopt a spatial Markov chain approach to determine the propulsive influence of a parcel's neighbors on its likelihood of undergoing change.

The insights that emerge from this spatio-temporal analysis highlight the causal processes of change that form urban landscapes. They also frame micro-level processes and urban morphology as a cause and effect relationship. A better assessment of the pattern and allocation of nuisance, hazard, or other incompatible uses in a rapidly growing metropolis may also inform decision-making in regions around the world that have similar growth trajectories as Phoenix. A historical approach to urban pattern is especially useful. New Urbanist ideas about walkability and land use complementarity are mostly derived from historic cities and continue to grow in popularity amongst planners (Berke 2002, Talen 2005, Jacobs 1961). Planners and policymakers seeking to increase the sustainability of urban neighborhoods and cities can utilize insights from these quantitative parcel-level analyses instead of simply romanticizing pre-war urban form. Rather than describing the past or attempting to model future growth, we conduct a quantitative, historical analysis of one city that is emblematic of automobile sprawl, seeking to observe how the past trajectory of parcels yielded a historic landscape so as to better understand how current processes can yield future landscapes.

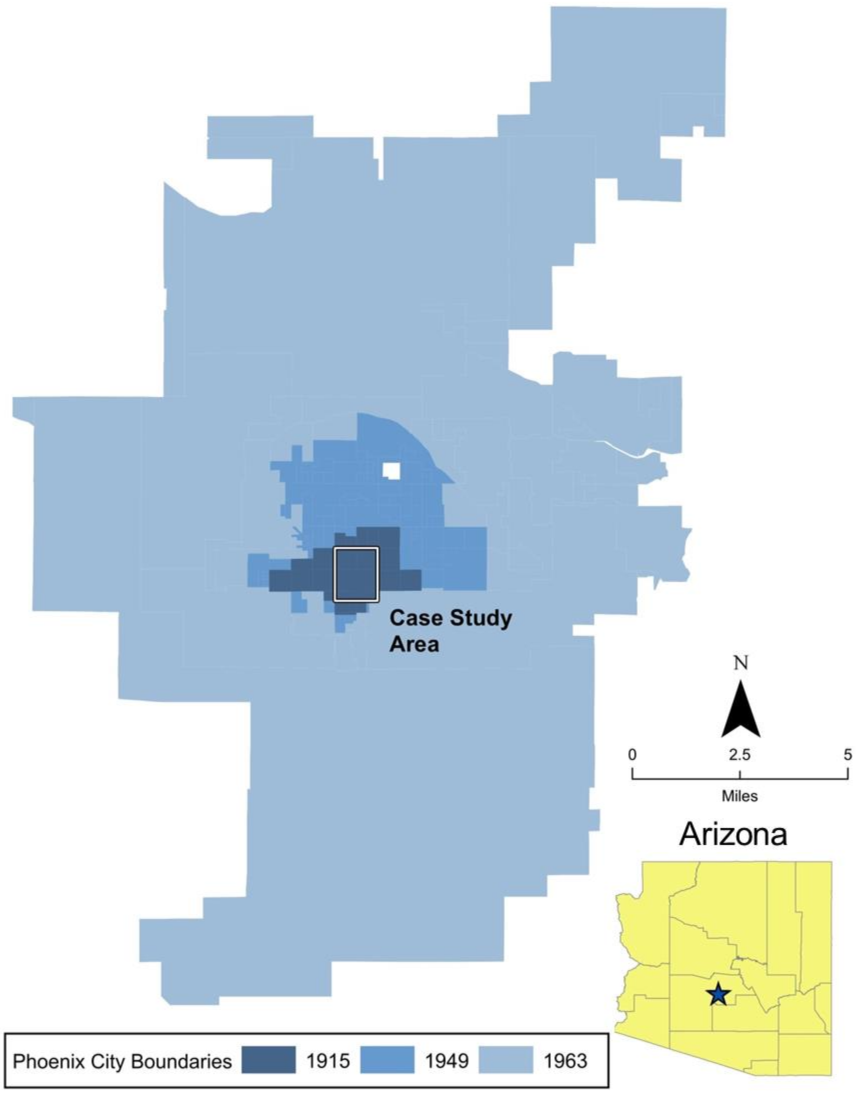

Figure 2.1: The expanding boundary of Phoenix, Arizona

2.1.1 Phoenix Urban History – A Background

Known as a booster-driven boomtown, Phoenix, while not even settled by Westerners until after the Civil War, has maintained one of the nation's highest urban population growth rates for a century. However, it continually appears in the academic literature as a cautionary example for what is wrong with urbanism: a dismal early record of racial intolerance and inequality, a lack of place and identity (Gober 2006), degraded perceptions of life quality (Guhathakurta and Stimson 2007), and the environmental implications of sprawled development (Bruegmann 2005). Several aspects of these historical narratives are inherently linked to urban morphology: Phoenix is known for its polycentric urban development – rather than a single, strong core like older cities, it is characterized by several functional subcenters that provide a measure of organization by economic sector (Leslie and Ó hUallacháin 2006). Following early-century flooding, an expansion of railroad-related industrial activity to the South, and an increase in the availability of land, there was a notable residential shift as wealthier, white, non-Hispanic residents gradually moved north while poorer, minority residents remained in South Phoenix. Land use homogenization and land use incompatibility existed side-by-side, but for different groups of people (Gammage 1999, Gober 2006). As the city's functions spread to subcenters and lower density outlying municipalities, the loudest complaints have come from concerns over energy use (automobiles and air conditioning), landscape degradation, and in broader and more recent vein, both weather and climate (Ross 2011).

This article focuses on a less explicitly (and less commonly) addressed concern regarding the fate of the historic downtown central business district. Not only is the dynamic of the CBD tractable at the parcel level, but it is also emblematic of many of the broader concerns about Phoenix's growth and suburbanization. Many drivers of regional land-use change are reflected in the story of the CBD. Though Phoenix is frequently derided for its low-density postwar sprawl, it had a vibrant downtown core during its evolution from a frontier town to a veritable boomtown. Early Phoenix development followed a typical Western narrative of settlement in an agriculturally productive river valley with railroads fostering upward and outward growth (York et al. 2011b). Phoenix, however, stood out from other cities because of its centralized political power and lax annexation policies (VanderMeer 2002). The perception of downtown decline – at least decline relative to the rest of the metropolitan area – is supported by data: from 1948 to 1963 the CBD's share of Maricopa County retail sales dropped from 35% to 7.7% (Luckingham 1989). Sternlieb (1963) argues that nationwide, the decline of downtown retail reflects deep-seated social changes related to the isolation of downtown shopping from the homes of middle-class, white customers. Suburbanization thus had a direct impact on the relationship between land use types in the downtown core. The recent emphasis of New Urbanists such as Talen (2005) and Duany et al. (2010) on mixed uses and community building in downtowns highlights efforts to reverse the negative legacies of homogeneity that impacted the landscape of downtowns during periods of suburban expansion. Their focus on downtown renewal also calls for empirical analyses of the histories of central cities.

In contrast to the homogeneity that dominated suburban developments, the siting of undesirable properties near residential neighborhoods, particularly in low-income and minority neighborhoods, created an unwelcome heterogeneity that has been ignored or even promoted at the municipal level throughout Phoenix's history (Bolin et al. 2005).

Kivell (1993) notes the role played by postwar industrial decline in changing urban landscapes. Changes in one sector – industrial, in his example – lead to altered patterns of land use in other sectors such as housing and utilities. This creates a haphazard land use pattern with remnants of industry interspersed with some housing and a high quantity of vacant or public open space, as the rate of commercial or industrial decay often outpaces the ability of a city economy to absorb non-wealth producing land. Again, a structural economic change drives a change in the relationship between different land use types in a city, though in this instance the result is land use incompatibility. The lack of effective institutional controls on land use and capital outflow within an area in a rapid state of flux such as postwar Phoenix may yield an urban landscape where lower order, industrial uses create a nuisance for nearby higher-order residential or retail uses. This contention is congruous with Phoenix's environmental justice and downtown decay narratives and underscores the importance of understanding the spatial distribution of nuisances and hazards as the city changes.

2.1.2 Quantitative Urban Growth Analysis – Background

While some urban researchers utilize a historical narrative approach based upon qualitative evidence (see Kallus (2001), for example), quantitative analysis of intraurban form has a rich history dating back to von Thunen's nineteenth-century concentric model to explain location rent (von Thunen 1966). The Chicago School of urban sociology extended this method to city growth patterns during the 1920s, while further models such as Adams (1970) incorporated transportation-based growth. More modern, computationally-intensive models have been led by cellular automata and agent-based modeling, which combine an initial state of land use with a set of decision rules to predict urban growth outcomes (Batty 2005). In addition, econometric models have been used to estimate determinants of rural land conversion at the urban fringe (Carrion-Flores and Irwin 2004), while metrics like patchiness and fractal dimension have also been developed to characterize the extent and form of urban land conversion (Seto and Fragkias 2005). Remote sensing and ecological models are particularly promising for use in analyzing urban land conversion (Verburg 2004). Pontius (2000), Pontius et al. (2004), and Pontius and Millones (2011) provide a generalizable land use transition framework that relies on a series of transition matrices between land use categories to measure both the quantity and allocation of populations, thereby sharpening the grasp on landscape change processes by including measures of persistence, loss, gain, and swap. Pontius proposes decomposing landscape change into quantity disagreement and allocation disagreement: the former representing the amount of mismatch due to different populations in each category and the latter showing the difference as observed on a map due to changing spatial allocation of the categories (Pontius and Millones 2011).

Geographical models that explicitly model spatial relationships can also be used to quantitatively assess urban landscape change, which follows from an interest in geographic statistics dating back to the 1960s. Join-count tests, first introduced by Dacey (1965) and refined by Cliff and Ord (1973), quantify the number of instances that two phenomena exist near each other in space. Join-counts can be used in a wide variety of contexts to analyze spatial autocorrelation in terms of deviation from a random, expected value or in terms of how the spatial relationships between observed phenomena change over time. Bell, Schuurman and Hameed (2008) use join-count tests to determine whether occurrences of non-accidental injuries are spatially autocorrelated based on whether they are significantly different from an expected value, while Rey, Mack and Koschinsky (2012) use join-counts over time to analyze the changing spatial patterns of residential burglaries. Vaughan et al. (2005) create a measure of proximity similar to join-counts for historic geographic data from London which is used to determine how spatial segregation varies by income class.

Wood et al. (1997) propose a spatial Markov approach for land-use change modeling, suggesting that land use transitions can follow a first-order Markov process. Rey (2001) provides a number of methods whereby spatial dependence can be integrated into a Markov chain transition matrix framework. Neighborhood conditioning asks how the likelihood of transitioning from one income class to another depends on the income class of your neighbors, defined (somewhat arbitrarily) as spatial units sharing a common boundary or vertex. This allows the researcher to determine whether the likelihood of transitioning from one category to another differs in the presence of certain neighbors. This approach can provide insights into the emergent properties of Phoenix's urban landscape such as trends toward homogenization, mixing of uses, or land use incompatibility. Spatial analytic approaches are particularly well suited to understanding how parcel-level land-use changes impact urban morphology.

2.2 Methods

The objective of this paper is to provide an empirical, parcel-level analysis of land-use change in Phoenix and compare these findings to drivers of change from historical narratives. It addresses quantity disagreement, allocation disagreement, and spatial outcomes at the finest possible resolution using four approaches described below, which are drawn from quantitative traditions in urban growth modeling, ecological modeling, and spatial analysis. Using these methods, this paper addresses three questions about which parcels are changing and in what way: (1) what landscape results from the changing composition of the downtown that accompanied postwar suburban dominance, (2) to what extent is land use homogenization or incompatibility observable, and (3) how do nuisances and hazards become distributed as the city changes? This empirical approach may be used as a model for researchers interested in better understanding dynamic urban regions in the past and today.

2.2.1 Data and Spatial Extent

Sanborn Fire Insurance Maps are first digitized for the historic, central core of Phoenix, Arizona from 1915, 1949, and 1963 spanning west from 7th Street to 7th Avenue and north from Grant Street to Roosevelt Street using 1915 parcel footprints in the instances where parcels change (Figure 2.2). While Sanborn maps contain an impressive amount of detail, parcels have been condensed into four general categories to loosely reflect the ordering of land use that characterizes Phoenix's Euclidean zoning: residential, commercial/institutional, vacant/parking, and nuisance/hazard. A detailed description of what falls into these categories can be found in Table 2.1.

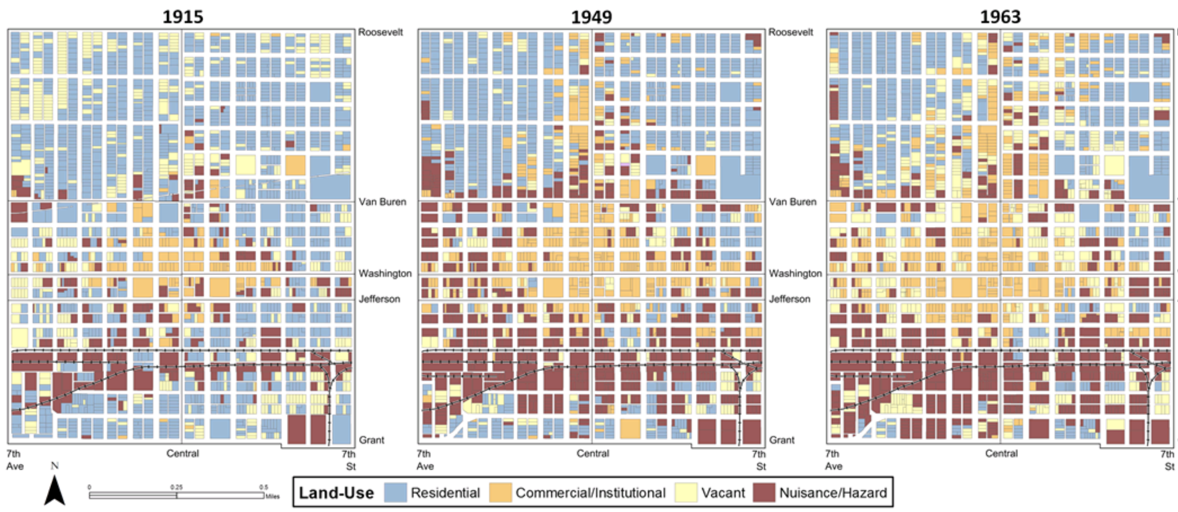

Figure 2.2: Phoenix parcels by land use category. The study area consists of 2378 parcels standardized to 1915 boundaries.

Land Use Category	Examples of Uses
Residential (R)	Single- and two-family homes, apartments, boarding houses, lodgings, tenements, cabins, shanties, churches, schools, parls, clubs, home stables.
Commercial/Institutional (C)	Retail, restaurants, hotels, offices, neighborhood groceries, health services, government offices, public services, armories, hospitals.
Vacant/Parking (V)	Vacant parcels, parcels subdivided for residential use, parking lots, parcels containing vacant or damaged structures.
Nuisance/Hazard (N)	Warehouses, wholesale suppliers, lumberyards, scrap yards, transportation distribution facilities, light manufacturing, repair and maintenance facilities, automotive services and standalone parking garages, stables, paint shops, vet hospitals, blacksmiths, laundry and dry cleaning, upholstering, oil storage, mills, ice manufacturing and cold storage, chemical storage and manufacturing, steel manufacturing, electric power stations, iron works, rail yards, and railroad tracks.

Table 2.1: Detailed description of land use categories

Phoenix's ever-expanding boundaries and rapid pace of growth make it somewhat difficult to define an appropriate spatial extent for the CBD. In defining the study area, boundaries and time points were selected to capture two very different growth periods: Phoenix as a "frontier boomtown" from 1915-1949 and then as a "postwar boomtown" from 1949-1963. By 1915, a variety of events had set the stage for growth and change in urban form, including the completion of the Roosevelt Dam, a move away from a geographically-elected city council, and early adoption of automobile transportation (Luckingham 1989). By 1949, the so-called Valley of the Sun had grown steadily, augmenting its reputation as a desert oasis with huge amounts of federal investment from the New Deal and World War II. By 1963, substantial demographic shifts began to change the residential arrangement of the Phoenix Valley toward one of tract homes farther from the city. This was due in part to Federal Housing Authority subsidies that led to the creation of so-called "developer suburbs" (Gammage 1999). The downtown core remained largely static between the late 1960s and the most recent period of urban renewal in the 1990s and 2000s, during which time the bulk of the region's growth and change took place outside the CBD.

2.2.2 Quantity Disgreement

First, quantity disagreement between land uses is observed by simply counting the parcels and using row-standardized transition matrices, displaying the number of parcels N in each category i at time t_0, then comparing to N_j at time t_1. This follows the foundation of a hazard of change approach taken by Irwin et al. (2003). The number of parcels that undergo a transition from category i to category j is denoted as N_{ij}. The row-standardized transition probability P_{ij} is the proportion of parcels that are in category j at t_1 for each category i in t_0. The expected number of parcels experiencing each transition type N_{ij} is given by E_{ij}

$$E_{ij} = \frac{N_i \times N_j}{T}$$

where N_i is the number of parcels in category i at t_0, N_j is the number of parcels in category j at t_1, and T is the total number of parcels in the study area (2378). E_{ij} is referred to as the population-predicted value. A pseudo-significance p-value based on series of random permutations of land use is also calculated:

$$p = \frac{m+1}{n+1}$$

where m is the number of permutations in which the observed transition count is greater than the expected value and n is the total number of permutations.

2.2.3 Allocation Disgreement

Next, allocation disagreement is observed using Pontius' metrics for persistence, gain, loss, and swap, providing a formal metric for spatial allocation changes that might be casually observed on a map. Statistical analysis of land use transitions is complicated by the fact that each transition type represents only a portion of a joint distribution. Pontius et al. (2004) suggest that the classical, statistical method for analyzing land-use change would be to generate an expected value based on populations, then use a chi-square test to determine if the entire distribution is significantly different from random – a relatively useless exercise because "scientists usually already know that persistence dominates the landscape" (Pontius et al. 2004). The persistence score is born out of the idea that there can be a change in the locational distribution of parcels of a certain category even if their count is the same in both periods. Thus, a parcel that "persists" exhibits the same use in both periods, while a "gain" parcel transitioned into that category over the time period and a "loss" parcel left the category. For example, a residential neighborhood may be demolished – say, in the case of Phoenix's Chinatown – and another one built elsewhere. In this hypothetical, the loss in residential is equal to the gain. The extent to which gain and loss offset each other (formally, the absolute value of the difference) is called "swap" and indicates a shifting allocation of parcels.

2.2.4 Spatial Relationships I: Join-Count Statistics

Next, spatial relationships are modeled with join-counts to measure the likelihood of particular use types existing in close proximity. Though gain, loss, and swap metrics can indicate that a use type is moving, they provide no detail as to where this may be happening nor do they offer any insights about the resulting spatial arrangement of the urban landscape. Since the social purpose of the built environment can be strongly informed by geographic pattern (Talen 2011), join-counts are an appropriate method for analyzing the neighborhood-level effects of parcel land-use change by quantifying the homogeneity or compatibility of land uses in an area.

The classic way to define a join is if two polygons have a boundary of positive nonzero length in common (Cliff and Ord 1981). However, parcels in a GIS environment do not achieve contiguity because parcels across the street do not share a boundary and would not be identified as neighbors. A set of *k* nearest neighbors or a threshold distance based on parcel centroids is insufficient as well. Many parcels in Phoenix are more than twice as long as they are wide, resulting in two parcels over being considered a neighbor before the parcel across the street is identified. Heterogeneity in parcel size and street width preclude a centroid-to-centroid threshold distance from being meaningful because of its tendency to miss joins involving large parcels. To circumvent these problems we draw a 200-foot buffer around the boundary of each parcel and identify any other parcel with portions lying within the buffer to be the target parcel's neighbor. Using this spatial weights scheme, parcels in the study area have between 4 and 43 neighbors with a mean of 20 and a standard deviation of 4.27. This distance – and the resulting number of neighbors – is intended to measure what a person might see and feel when she walks out the front door rather than providing a measure of accessibility or accounting for the effect of adjacent parcels only.

Join-counts are most commonly used in a binary (B = black and W = white) situation in which the three possible outcomes are BB, WW, and BW, with the first two representing positive spatial autocorrelation. Examples using more than two categories are rare, though Zhang and Zhang (2008) explore the six unique join types that would result from a trinary scheme: black, white, and grey. The use of four land use categories results in ten unique join types. While comparing the number of a particular type of join-count over time can be informative, it can also be misleading because the number of parcels in each category changes. Therefore, an expected count for each join type is calculated given the number of parcels in each category, their arrangement, and assuming they are randomly arranged. For joins of the same category *i* an expected value *E* with replacement is used:

$$E_{ii} = \frac{n_i(n_i - 1)}{n(n-1)} \times J_T$$

where *n* is the total number of parcels in the study area and J_T is the total number of joins possible based on parcel shapes and the spatial weights specification used. For joins between different land use categories *i* and *j* the formula changes slightly:

$$E_{ij} = \frac{n_i n_j}{n(n-1)} \times 2J_T$$

A series of random permutations is again used to test the null hypothesis of whether a particular type of join occurs more (or less) frequently than expected. A pseudo-significance value *p* is constructed, equal to

$$p = \frac{m + 1}{n + 1}$$

where *m* is the number of permutations in which observed joins are greater than the expected value and *n* is the number of permutations. While a high number of permutations yields a robust pseudo-significance value, if similar land uses are expected to cluster even thousands of random permutations might not produce a single instance where the observed joins are greater than the expected joins. Thus it may still be useful to conduct a simple comparison of observed and expected join-counts over time.

2.2.5 Spatial Relationships II: Spatial Transition Matrices

The final analysis uses spatial transition matrices as proposed by Rey (2001), who found that U.S. states are more likely to move up in the income hierarchy if they have rich neighbors and vice versa. His research addresses the discussion of regional income convergence, which was concerned with the homogenization of regions by income. Similarly, this investigation seeks to understand changing interactions between city parcels by land use, including homogenization. More concretely, this method is used to investigate the propulsive influence of a parcel's neighbors on its likelihood of undergoing a certain type of transition. A challenge arises in that land use data are categorical rather than a continuous, such as in the case of an income distribution. Binary categorical variables have been used in certain applications, such as Rey et al. (2012) who define a cell as "crime" if any of its neighbors have experienced a crime. This can be adapted for a four-category variable by identifying which of the four land uses is exhibited by a plurality of a parcel's neighbors, with neighbors being defined using the same 200-foot buffer as for join-counts. This is called a parcel's spatial lag, and the result is a decomposed form of the standard transition matrix showing how the likelihood of certain transition types is affected by a parcel's dominant neighbor pattern.

2.3 Results

Owing to the wealth of information that can be gathered from these methods, the analysis of results is tailored toward the Phoenix-specific phenomena in the original research questions: (1) what landscape results from the changing composition of the downtown that accompanied postwar suburban dominance, (2) to what extent is land use homogenization or incompatibility observable, and (3) how do nuisances and hazards become distributed as the city changes?

Within each subsection below we analyze whether our quantitative indicators support the contentions about the driving forces of land-use change from the historical narratives of Phoenix.

2.3.1 Quantity Disagreement: Phoenix Parcel Counts

Several trends are observed from simply counting parcels. Both commercial/institutional and nuisance parcel counts increased substantially (nearly tripling) by 1949 and remained relatively constant until 1963 (Table 2.2). The number of vacant parcels decreased substantially by 1949, then more than doubled. A steep and constant decrease occurred in residential land use over both periods. Interestingly, by 1963, parcel land use was almost evenly divided amongst the four classes (Figure 2.3).

	1915		1949		1963	
Land Use Category	Parcels	Percent	Parcels	Percent	Parcels	Percent
Residential (R)	1371	58%	995	42%	720	30%
Commercial/Institutional (C)	178	7%	471	20%	530	22%
Vacant/Parking (V)	547	23%	232	10%	483	20%
Nuisance/Hazard (N)	282	12%	680	29%	645	27%

Table 2.2: Phoenix parcel counts by category. The study area contains 2378 parcels.

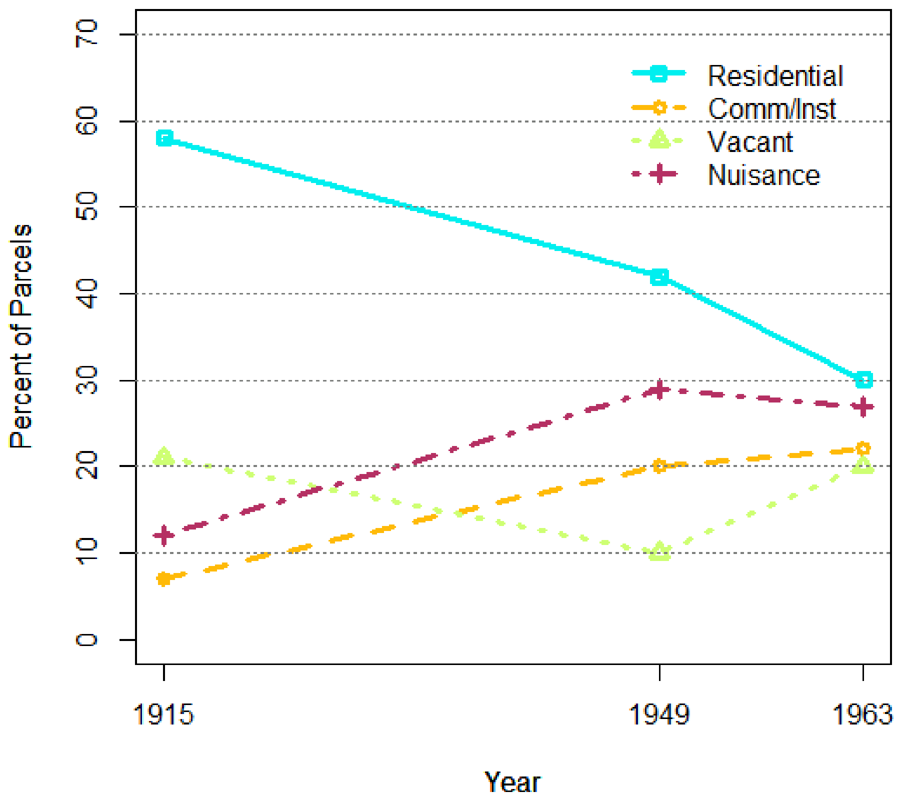

Figure 2.3: Phoenix land use by category (percent of total parcels)

The parcel counts are generally consistent with historical events. The region received substantial federal support before and during World War II in the form of New

Deal projects, so much that Del Webb, the region's leading construction magnate, remarked, "Construction is no longer a private enterprise, but rather a subsidiary of the federal government" (Luckingham 1989). The decrease in vacancy and the increase in commercial and nuisance (mostly industrial) parcels reflect the overall growth in Phoenix's early period. Downtown residential declines are expected, and are likely reflective of the continual trend of affluent whites moving north, both within Phoenix and to newer suburbs (Gober 2006). By 1963, commercial and nuisance uses retained a similar proportion of parcels from the previous period, while a distinct change occurred as residential counts declined and the number of vacant parcels more than doubled. Thus, we see evidence of the emptying of the downtown area; however, the main loss of built parcels appears to be residential and not commercial. Even though retail/commercial parcels are combined with institutional land uses in our analysis, this appears to contradict the assumption that retail decline and the construction of far-flung shopping malls were the driving factor in the downtown's decline.

2.3.2 Quantity Disagreement: Land Use Transition Analysis

Land use transition matrices for the frontier boom period and the postwar boom period can be found in Table 2.3. All use types except vacant are more likely to stay the same than to transition, which is expected as this category represents either a lack of land use or, in the case of surface parking, the lack of substantial built investment in its use. Given a null hypothesis of land use persistence, off-diagonal transition types should occur significantly less frequently than the expected value based on population. Any deviation from this pattern is noteworthy and is indicated by pseudo-significance values other than 1.000, which show that in the 9999 permutations run, there were at least some instances where that transition type occurred more frequently than expected by random chance.

	1949 Parcel Land Use					1963 Parcel Land Use			
1915 Parcel LU	R	C	V	N	1949 Parcel LU	R	C	V	N
Residential (R)	**797**	**180**	**95**	**299**	Residential (R)	**661**	**78**	**189**	**67**
	58%	*13%*	*7%*	*22%*		*66%*	*8%*	*19%*	*7%*
	[574]	[272]	[134]	[392]		[301]	[222]	[202]	[270]
	0.0001	*1.0000*	*1.0000*	*1.0000*		*0.0001*	*1.0000*	*0.9197**	*1.0000*
Comm/Inst (C)	**7**	**150**	**5**	**16**	Comm/Inst (C)	**25**	**330**	**57**	**59**
	4%	*84%*	*3%*	*9%*		*5%*	*70%*	*12%*	*13%*
	[74]	[35]	[17]	[51]		[143]	[105]	[96]	[128]
	1.0000	*0.0001*	*1.0000*	*1.0000*		*1.0000*	*0.0001*	*0.0001*	*1.0000*
Vac/Park (V)	**174**	**82**	**112**	**179**	Vac/Park (V)	**23**	**34**	**115**	**60**
	32%	*15%*	*20%*	*33%*		*10%*	*15%*	*50%*	*26%*
	[229]	[108]	[53]	[156]		[70]	[52]	[47]	[63]
	1.0000	*0.9995**	*0.0001*	*0.0094**		*0.0001*	*0.9989**	*0.0001*	*0.6926**
Nuis/Hazard (N)	**17**	**59**	**20**	**186**	Nuis/Hazard (N)	**11**	**88**	**122**	**459**
	6%	*21%*	*7%*	*66%*		*2%*	*13%*	*18%*	*68%*
	[118]	[56]	[28]	[81]		[206]	[152]	[138]	[184]
	1.0000	*0.3340**	*0.9594**	*0.0001*		*1.0000*	*1.0000*	*0.9713**	*0.0001*

N_{ij} **Number of parcels (Bold)**

P_{ij} *Row standardized percent (Italics)*

E_{ij} [Expected Value] (brackets)

p-value (* if different from expectation of persistence)

Table 2.3: Transition matrices showing change in land use category, expected values, and simulated significance *p*-values.

In the frontier boom period, the vacant-to-commercial (p = 0.9995) and vacant-to-nuisance (p = 0.0094) transitions were nearly as high as or higher than predicted by their raw counts, indicating an expansion of business and industrial activity into previously undeveloped land. Nuisance-to-commercial (p = 0.3340) and nuisance-to-vacant (p = 0.9594) transitions also occurred with high frequency. In the postwar boom period, residential-to-vacant (p = 0.9197) and nuisance-to-vacant (p = 0.9713) transitions approached the population-predicted values, corroborating the earlier result of residential exodus from downtown, but now suggesting that industry may have been leaving too. However, vacant-to-commercial (p = 0.9989) and vacant-to-nuisance (p = 0.6926) transitions were not substantially lower than population-predicted values, indicating that the trend toward vacancy was not universal.

2.3.3 Allocation Disagreement: Pontius Transition Scores

Results for Pontius' metrics can be found numerically in Table 2.4 and graphically in Figure 2.4. In the frontier boom period, the measures for persistence, loss, gain, swap, and total change are relatively straightforward and are expressed as a proportion of the total distribution. The aforementioned nuisance gains are offset with slight loss, while vacancy losses are offset with slight gain. Commercial/institutional gains are substantial and are accompanied by virtually no losses. Residential losses, while substantial, are slightly offset with residential gains (0.08). The postwar boom period shows a much more dynamic picture of change, especially because the data cover a much shorter time period (fourteen years as opposed to thirty-four). Simple counts of land use types suggest that the vacancy increase in this period was due to the decrease in residential use, and the scores in Table 2.4 confirm that residential loss was hardly accompanied by residential gains elsewhere. Evidence of commercial exodus is now found: commercial/institutional, despite a slight net gain, shows a high amount of swap and total change. This likely reflects a decrease in commercial use and an increase in government presence downtown, which was known to have happened during this time. Nuisance parcels exhibit a similar pattern of high swap, indicating that nuisance properties are changing in type and location as well. Finally, the swap statistics corroborate the transition matrix's finding that suggest the "emptying of the CBD" may not have been as bleak as is commonly thought: despite vacancy gains there was also a fair amount of vacancy loss (0.05) in addition to the aforementioned gain in commercial and nuisance parcels.

	Frontier Boomtown: 1915-1949						
Use Type	P_i 1915	P_j 1949	Persistence	Loss	Gain	Swap	Total Change
R	0.58	0.42	0.34	0.24	0.08	0.08	0.32
C	0.07	0.20	0.06	0.01	0.13	0.01	0.15
V	0.23	0.10	0.05	0.18	0.05	0.05	0.23
N	0.12	0.29	0.08	0.04	0.21	0.04	0.25

	Postwar Boomtown: 1949-1963						
Use Type	P_i 1949	P_j 1963	Persistence	Loss	Gain	Swap	Total Change
R	0.42	0.30	0.28	0.14	0.02	0.02	0.17
C	0.20	0.22	0.14	0.06	0.08	0.06	0.14
V	0.10	0.20	0.05	0.05	0.15	0.05	0.20
N	0.29	0.27	0.19	0.09	0.08	0.08	0.17

Table 2.4: Various scores, described in Pontius et al. (2004) that provide greater intuition on allocation disagreement found in a transition matrix. P_i and P_j are the proportions of parcels in this category in the initial and final periods, respectively. Persistence refers to the proportion of parcels that were in land use category *i* in both periods, while gain and loss refer to the proportion of the total distribution that entered or left category *i*, respectively. Swap is the absolute value of (gain – loss), and total change is (gain + loss).

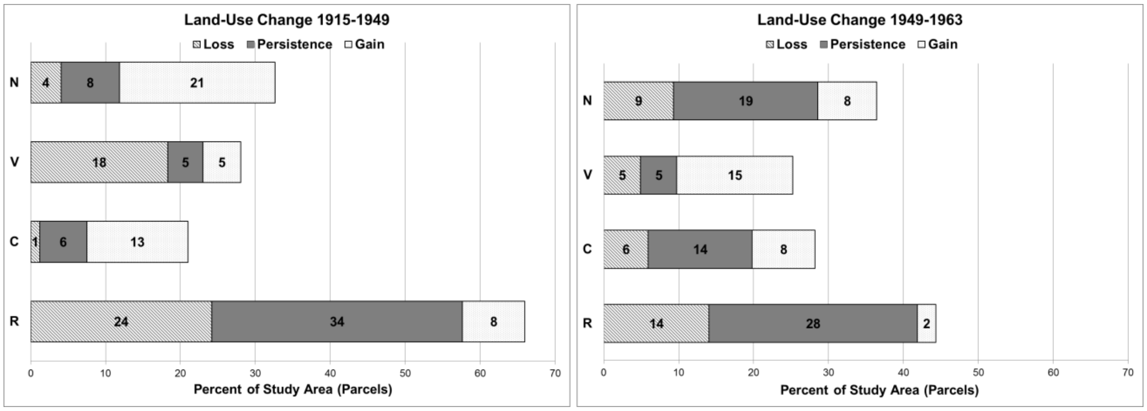

Figure 2.4: A graphical representation of Pontius' loss, persistence, and gain metrics observed from the perspective of a land use category. For example, nuisance properties in 1915 represent 12% of the total parcels in 1915: 4% of the total distribution represents nuisance parcels that were to become something else by 1949, while 8% represents parcels that persist as nuisance over 1915-1949. Similarly, nuisance properties in 1949 represented 29% of the total parcels in 1949: the 8% that persisted, plus the 21% representing nuisance parcels that were something else in 1915 (gain).

2.3.4 Spatial Relationships: Join-Count Statistics

Table 2.5 displays all ten types of join-counts, along with expected values and a pseudo-significance value based on random permutations. The observed values for the four types of join-counts involving the same land use are significantly greater than their expected values for each year and, in most cases, the observed value is quite substantially greater than the expected value. Conversely, there are only three instances in which the observed value of joins between different land use types is statistically close to the expected value; in two cases it is actually greater than expected. This suggests a strong propensity toward clustering of same land uses. To analyze how counts changed over time, observed versus expected counts for selected joins are shown graphically in Figure 2.5.

	1915			1949			1963		
Join Type	Observed	Expected	p-value	Observed	Expected	p-value	Observed	Expected	p-val
C:C	914	134	*0.0001*	2393	945	*0.0001*	2648	1197	*0.0001*
N:N	943	338	*0.0001*	3670	1970	*0.0001*	3579	1773	*0.0001*
R:R	10062	8016	*0.0001*	7645	4221	*0.0001*	4963	2209	*0.0001*
V:V	2014	1275	*0.0001*	403	229	*0.0001*	1618	994	*0.0001*
N:C	587	428	*0.0001**	2110	2734	*1.0000*	1658	2918	*1.0000*
R:C	783	2083	*1.0000*	1731	4000	*1.0000*	1566	3257	*1.0000*
R:N	2169	3300	*1.0000*	2401	5775	*1.0000*	1500	3964	*1.0000*
V:C	278	831	*1.0000*	746	933	*1.0000*	2081	2185	*0.9908**
V:N	1023	1317	*1.0000*	1450	1347	*0.0024**	2240	2659	*1.0000*
V:R	5350	6401	*1.0000*	1574	1970	*1.0000*	2270	2968	*1.0000*

*instances where joins of different types are greater than, or not significantly different from expected values

Table 2.5: Observed and expected join-counts with simulated significance p-values.

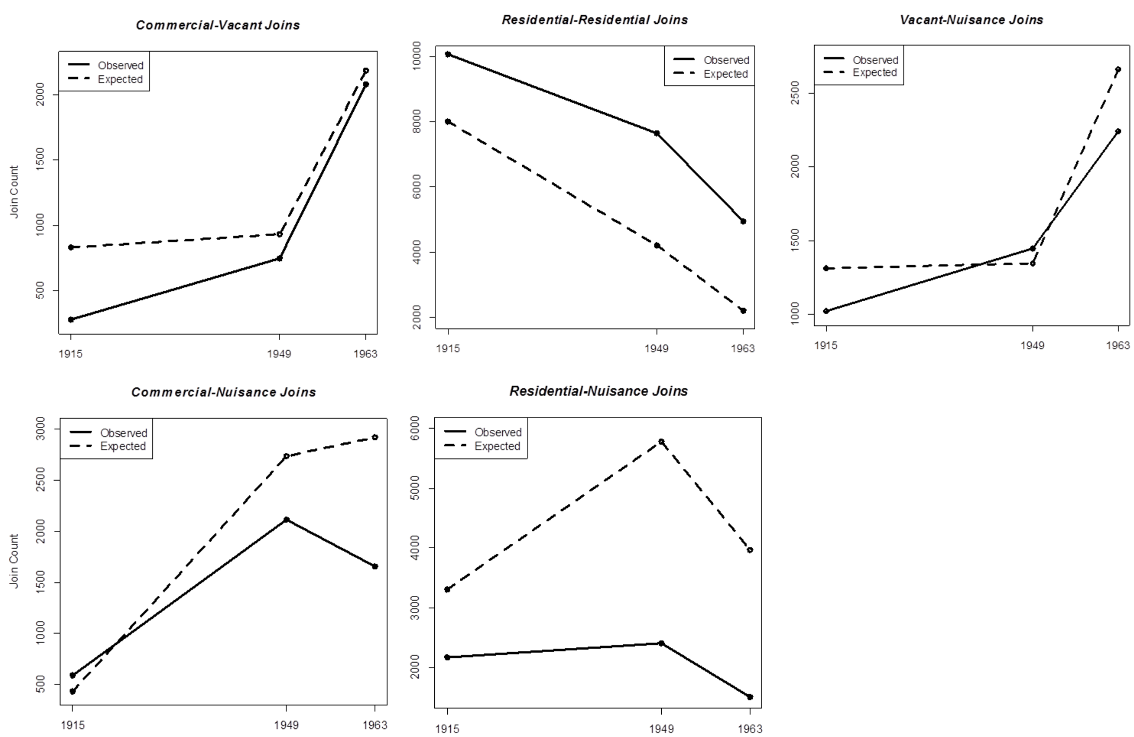

Figure 2.5: Selected join-counts showing actual (observed) values and expected values based on the number of parcels in each category, their shapes, and the assumption that they are randomly arranged.

In order to examine the character of the commercial outflow from downtown, we observe commercial-to-vacant joins. A low starting value, combined with far higher than expected commercial-commercial joins in 1915 indicates a tightly spaced commercial district. By 1949, the observed and expected values of commercial-vacant joins began to converge and by 1963 the observed count was only slightly below expectations – so much that there is a slight statistical chance ($p = 0.9908$) that commercial/institutional parcels are as likely to be within 200 feet of vacant parcels or surface parking as their raw counts suggest.

The residential-residential join-count is far above the expected value in all cases and is not statistically significant. Despite fewer residential parcels, the residential-residential join-count continually increases relative to the expected value, indicating residential homogenization consistent with the story of wealthier, white, non-Hispanic residences continually pushing north from the CBD. Thus, we find evidence of an urban landscape where commercial parcels are found in close proximity to recently vacated former residences, which is consistent with the results from the transition matrices.

Additionally, though the idea of downtown decay might be consistent with incompatible land uses – especially with weak zoning regulations – there is a noteworthy change in the joins related to nuisance properties. Commercial-nuisance joins actually begin above the expected value in 1915 but are significantly below it in 1949, indicating that these uses – once exhibiting a high propensity toward clustering – are sorting out even though this relationship is substantially more common. Then, despite an expectation of a slight increase, they drop precipitously during the postwar period. Residential-nuisance joins are not significantly similar to expected values though their change over time is interesting. Despite a large expected increase, they stay relatively stable during the frontier boom period, followed by a continued (but expected) drop in the postwar period. In both cases, we see a continual decrease in the instance of higher order uses existing in close proximity to nuisance parcels. It would appear as though nuisance properties are less likely to be a nuisance to their neighbors. Interestingly, the residential sorting away from nuisance was more pronounced in the frontier boom period while the commercial sorting was greater in the postwar period, indicating that the residential move northward and outward preceded the commercial changes downtown. Finally, vacant-nuisance joins are also indicative of somewhat haphazard growth in the frontier period followed by postwar sorting: lower than expected in 1915, they are significantly greater than expected in 1949, and drop below again in 1963.

2.3.5 Spatial Relationships: Spatial Markov Approach

The row-standardized transition matrices for both periods are shown as 4 x 4 x 4 matrices in Table 2.6. A byproduct of our categorical distribution is that the parcels represent actual land use types and are not arbitrary thresholds determined for this analysis, such as quartiles of a continuous income distribution. Therefore, some of our spatial lag designations can be sparsely populated, resulting in several lagged transition types that are undergone by only one or no parcels. In these instances, care must be taken not to overstate the importance of one's inferences.

Spatial Lag *Count*	LU Cat 1915	Land Use Category – 1949 R	C	V	N
R	R	*62%*	*11%*	*6%*	*20%*
	C	*14%*	*68%*	*11%*	*7%*
1591	V	*32%*	*18%*	*19%*	*31%*
	N	*7%*	*18%*	*6%*	*69%*
C	R	*15%*	*70%*	*7%*	*7%*
	C	*1%*	*92%*	*1%*	*7%*
186	V	*0%*	*67%*	*0%*	*33%*
	N	*7%*	*57%*	*10%*	*27%*
V	R	*57%*	*9%*	*7%*	*27%*
	C	*13%*	*38%*	*13%*	*38%*
383	V	*37%*	*10%*	*23%*	*30%*
	N	*9%*	*6%*	*9%*	*76%*
N	R	*2%*	*30%*	*19%*	*49%*
	C	*5%*	*79%*	*0%*	*16%*
218	V	*0%*	*6%*	*29%*	*65%*
	N	*4%*	*19%*	*7%*	*70%*

Spatial Lag *Count*	LU Cat 1949	Land Use Category - 1963 R	C	V	N
R	R	*71%*	*7%*	*17%*	*5%*
	C	*13%*	*55%*	*15%*	*17%*
1078	V	*28%*	*3%*	*56%*	*14%*
	N	*7%*	*8%*	*19%*	*65%*
C	R	*24%*	*33%*	*30%*	*12%*
	C	*3%*	*77%*	*12%*	*8%*
403	V	*0%*	*25%*	*47%*	*28%*
	N	*0%*	*19%*	*42%*	*39%*
V	R	*33%*	*17%*	*33%*	*17%*
	C	*0%*	*100%*	*0%*	*0%*
43	V	*4%*	*39%*	*43%*	*13%*
	N	*0%*	*23%*	*23%*	*54%*
N	R	*44%*	*8%*	*31%*	*17%*
	C	*6%*	*64%*	*11%*	*20%*
854	V	*0%*	*15%*	*46%*	*38%*
	N	*1%*	*13%*	*15%*	*72%*

Table 2.6: Row-standardized spatial Markov transition matrices, which are equivalent to the standard transition matrix decomposed into four categories representing a parcel's spatial lag. In some cases a certain spatial lag, such as vacant lag in 1949, is experienced by very few parcels. Thus the row-standardized transition probabilities should be interpreted with caution as they may represent very few actual land use transitions.

Neighborhood homogenization during the postwar boom period is tested using two comparisons in Table 2.7 – first by seeing whether a parcel's staying probability is affected by a spatial lag of its own category. For example, a commercial property has a 77% chance of remaining commercial if it has predominantly commercial neighbors whereas generally, a commercial parcel has only a 70% chance of remaining commercial. For all types except vacant, having similar neighbors increases a parcel's staying probability. Second, we observe a parcel's homogenization probability, which is the likelihood of the target parcel becoming like its neighbors if it isn't already. In all cases, a transition to category *j* is much more likely in a neighborhood dominated by *j* than overall.

Transition Type	Staying Probability: Similar Neighbors	Staying Probability: Overall
R → R	71%	66%
C → C	77%	70%
V → V	43%	50%
N → N	72%	68%

Transition Type	Homogenization Probability: Similar Neighbors	Homogenization Probability: Overall
i → R	16%	4%
i → C	24%	10%
i → V	42%	17%
i → N	24%	11%

Table 2.7: Conditioned staying probability and homogenization probability as derived from the full spatial Markov transition matrix, 1949-1963.

Spatial Lag	Commercial-to-Vacant: Parcel Count	Commercial-to-Vacant: Percent of Total
R	11	15%
C	33	12%
V	0	0%
N	13	11%
Total	*57*	*12%*

Spatial Lag	Residential-to-Vacant: Parcel Count	Residential-to-Vacant: Percent of Total
R	141	17%
C	10	30%
V	2	33%
N	36	31%
Total	*189*	*19%*

Table 2.8: Effect of neighborhood conditioning on select transition types, 1949-1963.

Taking a magnifying glass to the spatial transition matrix can also provide a closer look at the emptying CBD by observing how neighbor-conditioning affects two particular transition types (Table 2.8). Earlier results indicated high swap within the commercial/institutional category and an increasing count of commercial-to-vacant joins. However, no pattern of neighbors (spatial lag) seems to change the likelihood of a commercial property switching to vacant, though the power of this test is reduced by the rarity of this transition type. Residential-to-vacant transitions, on the other hand, are much more likely in nonresidential areas. This corroborates our earlier result that residential properties near other use types represent a noteworthy portion of the downtown parcels that become vacant by 1963.

2.4 Discussions

The previous section presented the results of each individual method. In this section we consider all results in light of our three research questions: (1) what landscape results from the changing composition of the downtown that accompanied postwar suburban dominance, (2) to what extent is land use homogenization or incompatibility observed, and (3) how do nuisances and hazards become distributed as the city changes?

First, the perceived emptying out of the CBD from 1949-1963 was more complex than just a retail exodus. Raw numbers suggest a shift from residential to vacant parcels. Pontius' metrics show high swap within the commercial/institutional category, suggesting that our aggregation of the two types may hide retail loss behind an increase in government presence downtown. Nonetheless, they indicate that commercial/institutional parcels are changing location, though not decreasing in total quantity. Join-counts show an increase in the likelihood of a commercial and vacant property being situated near each other. The spatial Markov matrix indicates this is likely related to residential exodus: residential properties are more likely to vacate if in commercial/institutional neighborhoods, leaving commercial parcels next to vacant ones. This creates a street-level atmosphere of languishing retail, government buildings, and other commercial/institutional properties which continues in Phoenix's downtown to this day.

The emptying of downtown can be seen very clearly on the map in Figure 2.2: a ring of vacancy seems to appear by 1963, surrounding the center of downtown in areas that look to have been a mix of uses in 1949. Our metrics indicate that, in terms of actual parcels, this decline was more directly tied to residential exodus than overall commercial decline, though these processes certainly operate hand-in-hand. This demonstrates the validity of Sternlieb (1963)'s understanding of positive feedbacks, wherein residential outflow moved middle-class customers away from downtown retail, which languished itself and eventually moved too. Furthermore, we see some evidence that this emptying out did not represent a wholesale hollowing out of economic activity which befell some older industrial cities like Detroit. Vacant-to-commercial and vacant-to-nuisance transitions continued to occur while Pontius metrics actually show some vacancy loss in the CBD.

Second, we see several indications of land use homogenization and a decline in the incidence of undesirable incompatibility. Most clearly, spatial Markov matrices indicate strong homogenization pressure during the postwar period, wherein a parcel is more likely to remain in the same category if it is near parcels of the same type and far more likely to change to the same land use of its neighbors if it is dissimilar. Join-counts and spatial Markov matrices suggest the decrease in residential parcels in downtown Phoenix is not characterized by vacant patches within residential neighborhoods. Instead, it reflects large-scale residential exodus. This is consistent with the commonly held narrative of white, non-Hispanic, and wealthier residences continually moving north within Phoenix and to the newly built post-war suburbs. Again, this can be seen on the map in Figure 2.2: by 1963 there appear to be far fewer residential parcels downtown and those that remain are heavily concentrated north of Van Buren Street.

Finally, we find evidence of a continual decrease in residential and commercial uses existing in close proximity to nuisance parcels in the study area. While industrial activity has always concentrated around the railroads in the southern portion of downtown, nuisance/hazard parcels become increasingly concentrated in these areas and other uses generally move elsewhere (which again can be seen in the map in Figure 2.2). This change is apparent in general terms as well: by 1949 nuisance parcels are decreasingly found in close proximity to residential areas and by 1963 their likelihood of being near commercial parcels drops sharply too. This provides evidence that Phoenix's downtown is increasingly ordered in terms of Euclidian land use categories despite concerns that rapid change, poor zoning enforcement, and capital outflow would result in incompatibility.

2.5 Conclusions

The goal of this chapter is to use parcel-level land use data from Phoenix to link land-use change processes from historical narratives to observed changes in urban morphology by drawing on quantitative traditions in urban growth modeling, ecological modeling, and spatial analysis. This approach helps us understand the connection between urban landscapes and the micro-level processes that lead to their creation. The insights gained are critical to pushing forward planning policies that recognize the role of parcel-level land use decision making and could be utilized by planners and New Urbanist scholars to empirically understand historical processes that led to the neighborhood and landscape patterns that they are either trying to avoid or recreate. Examining parcel-level change can lead to some emergent insights that may not be perceived with a broader narrative approach such as the role played by land use swapping within the commercial/institutional category or the importance of the residential exodus in downtown's commercial decline. Understanding changes in the way parcels are allocated in a city is an important component of urban revitalization and directly impacts walkability, land use complementarity, and ultimately urban sustainability. This examination and approach provide a step toward a more nuanced understanding of urbanization processes and patterns within an exponentially growing Sunbelt city.

The postwar downtown decline is emblematic of broader regional changes in Phoenix and is a key part in the story of automobile dependence and suburbanization. Unpacking the observed land use pattern suggests that landowners' parcel-level decision-making resulted in a pattern of commercial areas interspersed with vacancy, which helps to explain modern downtown Phoenix's swaths of vacant land and surface parking—legacies of a postwar downtown decline. While the extent of residential and nuisance properties' propensity toward sorting may have been unexpected given the CBD's decline, this study provides quantitative support for the narratives about northward residential movement and industrial concentration south of downtown.

Ongoing work (see Chapter 3) aims to link drivers of land-use change to land cover data, thereby extending the utility of a parcel-level analysis to more recent concerns about urban micro-climates and regional water use. A further approach that integrates similar space-time analysis with econometrics could model the impact of zoning policies or observe the effect of urban development subsidies on urban morphology, linking policy and land use outcomes directly (see Chapter 4). Historical legacies continue to determine the future trajectory of urban areas throughout the U.S. This quantitative, historical analysis of one city emblematic of automobile sprawl has improved the link between drivers of land-use change and urban morphology by showing how historic developments have transformed the urban landscape into what it is today.

CHAPTER 3

BEYOND FRAGMENTATION AT THE FRINGE

3.1 Introduction

Patterns of human settlement are changing rapidly around the world as the global population becomes increasingly urban. In addition, economic and social changes affect the pattern of land use and land cover within cities, altering the structure and form of urban environments. These changes in spatial structure in turn transform ecological functions, such as hydrological systems and biogeochemistry (Grimm et al. 2008). Changes in land cover and ecological process have far reaching impacts for ecosystem services, which in turn shape various social and economic outcomes (Tratalos et al. 2007, Bolund and Hunhammar 1999). As urbanization continues and urban spatial pattern evolves, research is needed to inform planning and management of urban areas, addressing the causes and impacts of different urbanization patterns (Longley and Mesev 2000, Klosterman 1999), which are heavily impacted by policy (Newburn and Berck 2006, Carruthers 2003).

Urban form and patterns of urban growth have long been of interest to geographers. This topic has been widely explored in relation to socioeconomic activities (see, e.g., Knox 1991), but more recently scholars have become interested in environmental implications: namely, how different spatial patterns in cities may impact ecosystem processes with implications for ecosystem services and adaptation to environmental change (e.g., Alberti 2005, Alberti and Marzluff 2004; Turner et al., 2013). Concerns for both socioeconomic and biophysical implications of urban spatial pattern are often aired in conjunction with critiques over urban sprawl. Definitions of urban sprawl vary, but the term generally refers to the excessive spatial growth of cities (Brueckner 2000), which is characterized by low-density development and automobile-dominated infrastructure and lifestyles (Bruegmann 2005). Considering the variety of phenomena encompassed, Ewing, Pendall and Chen (2002) suggest three specific spatial dimensions of sprawl: low-density population, new development on the periphery without a clear activity center, and widely separated built structures.

Additionally, the form and style of agglomeration is highly dependent on place and historical context (Bruegmann 2005). Urban spatial structure is heavily path-dependent (Arthur 1988), continuously characterized by the infrastructure and planning of past periods of development. The way a neighborhood looks today is largely reflective of the era during which it was built, "locking in" the effect of short-term housing booms, the principal economic activities of the time, and the dominant communication and transportation technology (Adams 1970, Anas, Arnott and Small 1998). Given these legacy effects of urbanization, understanding the characteristics of historical time periods during which growth occurred can inform the understanding of present-day landscape variation.

Research analyzing the detailed characteristics of patterns of sprawl has been supported by the increasing availability of spatial data and the development of new methods of spatial analysis. Whereas earlier geographic analyses were often limited by data availability, recent studies have benefited from the proliferation of earth observing (EO) sensors to examine specific changes in urban landscapes, and to evaluate theories of urban development (e.g., Dietzel et al. 2005, Taubenböck et al. 2014). EO methods provide the ability to examine regional, continental, and even global scales. At regional scales, sprawl studies have employed EO data to examine agglomeration around urban cores (Taubenböck et al. 2014, Dietzel et al. 2005) and to facilitate comparison between urban areas (Burchfield et al. 2006, Schneider and Woodcock 2008), examining changes in the extent of built-up areas or even changes in vertical structure across different cities (Frolking et al. 2013). These comparisons of urbanization around the world reveal distinct patterns of growth, suggesting that growth trajectories vary across cities (Schneider and Woodcock 2008). To facilitate such comparison and to capture the more nuanced characteristics of urbanization, Seto and Fragkias (2005) call for a diverse set of quantitative measurements that describe various facets of urban growth and that help to infer the underlying processes that drive observed urban forms. Similarly, Siedentop and Fina (2010) suggest that a multi-indicator approach should be used to identify three aspects of sprawl: urban density, pattern, and composition.

In order to characterize such aspects of urban spatial pattern, an increasing number of urban studies have employed an array of spatial metrics common in landscape ecology (Turner 1989). Spatial metrics provide measures of landscape pattern derived from the analysis of thematic-categorical maps, which first segment the observed landscape into patches of adjacent pixels of the same class and then use this information to quantify landscape patterns. Spatial metrics commonly provide descriptive measures of the spatial characteristics of individual patches, all patches in a given class, or all patches in the landscape. Various metrics have been developed (Turner et al. 1989, Li and Reynolds 1993) and implemented in different software packages, most notably FRAGSTATS (McGarigal and Marks 1994). Ecologists have long employed these tools because changes in the shape, size, prevalence, and connectivity of different land cover patches, as well as the positions of these land covers relative to each other, can have significant impacts on various ecological processes (Turner 1989, Turner, Gardner and O'Neill 2001). Studies of sprawl commonly incorporate these metrics, but often only identify two thematic classes that distinguish between “developed” and “undeveloped” patches. Nonetheless, EO datasets can support more complex classification schemes, which can be useful to characterize specific features of certain regions (for example, identifying structure types within informal settlements in the developing world, see Kuffer and Barros 2011, Banzhaf and Hofer 2008), but these are partially dependent on the resolution of the EO data.

In recent years, numerous studies have applied landscape metrics to the study of urban morphology (e.g. Wu and Webster 2000, York and Munroe 2010), most commonly employing moderate resolution data, such as Landsat and the National Land Cover Dataset (NLCD), which consist of 30m x 30m pixels. For example, York et al. (2011a) and Zhang et al. (2013) used Landsat-derived data to estimate metrics of fragmentation in several rapidly growing US cities and demonstrated that fragmentation typically increases with distance from the city center. McDonnell and Hahs (2008) review 300 papers that rely on the variation of urban intensity along an urban-rural gradient in order to understand differences in ecosystem processes, but little of this research has empirically assessed differences in detailed spatial patterns of land cover (beyond general categories of land use) or small scale habitats.

Moderate resolution analyses offer important information on regional scale change, but increasingly complex use of urban space necessitates a scale-sensitive, micro-level approach (Irwin, Jayaprakash and Munroe 2009) – a perspective shared by ecologists (Wu and Loucks 1995, Pickett et al. 1997). The moderate resolution imagery relied upon for most prior studies has proven useful for tracking the expansion of urban areas, but is ill-suited for capturing the fine details that characterize urban landscapes (Theobald 2001, Herold, Couclelis and Clarke 2005, Irwin and Bockstael 2007). For example, Burchfield et al. (2006), develop an index of sprawl using NLCD data and find that, across the entire US, the extent of scatteredness in urban areas was essentially unchanged from 1976 to 1992. Irwin and Bockstael (2007) challenge their conclusions, augmenting NLCD data with land use records in Maryland to demonstrate that fragmentation (using landscape metrics) is not static over time, does vary across an urban-rural gradient, and requires a finer resolution approach. Recognizing this need, some studies have begun to use landscape metrics to analyze finer resolution data to identify and characterize specific components of urban form. Taubenböck and Kraff (2013) used spatial metrics of high resolution data to identify the physical properties of slums in Mumbai using Quickbird imagery (0.6m resolution). Kuffer and Barros (2011) used Quickbird and Ikonos (4m resolution) in Dar es Salaam and Delhi to identify unplanned areas in cities. Similarly, Banzhaf and Hofer (2008) used object-based methods on aerial photographs to identify specific types of urban structures. In combination, these examples illustrate the potential application of high-resolution datasets and pattern analysis techniques to improved characterization of urban landscape features.

This paper analyzes fine-grained aspects of sub-metropolitan spatial pattern in Phoenix, Arizona based on when an area within the city was developed, relying on the path-dependent nature of cities to understand variation in present-day patterns of land cover. Urban morphology is largely the product of historical development trends, while the durability of built capital means that the environmental consequences of development will persist for several decades after the process that led to their construction has played out. In particular, Boone et al. (2012) argue that the timing of development is crucial for urban ecosystem structure and function. Put simply, different areas within a city are expected to have different landscape characteristics based on when they were built. This study adds to the literature above because it 1) uses higher resolution spatial data, 2) uses high thematic resolution (i.e., beyond developed/undeveloped), and 3) considers variation in spatial pattern by historical development periods rather than by intrametropolitan location. This study uses one-meter resolution NAIP (National Agriculture Imagery Program) images of Phoenix, Arizona from 2010, which has the ability to identify variation within parcels of land – including, for example, individual trees, sidewalks, and patches of lawn. Spatial metrics are used to identify four characteristics of land cover relevant to urban sprawl: area and density, fragmentation, shape complexity, and diversity. These metrics are analyzed across 946 sub-metropolitan units in Phoenix (census block groups) based on the time period in which they were developed in order to understand how present-day urban spatial pattern varies based on when areas of the city became developed.

3.2 Material and Methods

3.2.1 Study Area

Phoenix's urban history did not begin in earnest until the start of the twentieth century. The city's 1915 boundaries, generally considered to be the "original townsite" (York et al., 2014) encompass 10.4 square kilometers, while its 2012 boundaries include

2,079 square kilometers. Residential land use dominates the city in terms of land area, comprising 69% of the built-up area in its historic core in 1915 and 62% of the built-up area in 2012 (Kane et al. 2014c). The urban (developed) extent of the entire metropolitan area increased similarly from 48 square kilometers in 1934 to 2,537 square kilometers in 2010 (Knowles-Yanez et al. 1999 and authors' calculations).

Early growth in Phoenix followed a relatively concentric pattern extending outward from the Central Business District (CBD), facilitated by the limited presence of existing manmade features and the fact that automobile transportation was adopted fairly early in the city’s history (VanderMeer 2002). This pattern began to change in the early 1960s when the CBD ceased to be a major draw and growth became more polycentric and dispersed (Kane et al. 2014b). Development styles contrast dramatically across time periods, in Phoenix and in general (Judd and Swanstrom 2008, Gober 2006). Early homes and businesses of the 1920s, localized near downtown, were largely built in the same manner as in older cities. Mass-produced single-story tract homes characterized residential construction following World War II, while gated and master-planned communities became popular beginning in the 1970s. During the latter period, large shopping malls and office parks supplanted older commercial space in Phoenix’s CBD. Discussion of more recent changes typically focuses on fringe development, with the real estate boom that began in the late 1990s taking place most prominently farther from the city center (Gober and Burns 2002). This happened in “boomburbs” such as Chandler and Gilbert but also in the far northern and southern parts of the City of Phoenix. Atkinson-Palombo (2010) finds that growth during the early 2000s was more varied than the prior decade, with denser, multifamily housing near the urban fringe augmenting single-family development there. Additionally, conversion of former agricultural land ground to a halt during the 2006-2008 recession (Kane et al. 2014c).

3.2.2 Delineating Historical Periods

The purpose of this study is to investigate how spatial indicators of urban sprawl vary across areas within a city based on the time period during which present-day structures were built. While a city-wide indicator of sprawl may be interesting in a cross-site context, our goal is to capture sub-metropolitan variation in sprawl indicators, following the idea within urban design that geographic pattern informs a sense of place and drives the experiences of individuals (see, e.g., Talen 2011), and that environmental implications of development such as the urban heat island are often localized (see, e.g., Connors, Galletti and Chow 2012). Furthermore, the surroundings of an individual are not confined to a single land parcel, but also include the streets, public spaces, and other land uses nearby. Thus it is necessary to define an appropriate areal unit at which to analyze sprawl.

Prior studies such as Shrestha et al. (2012) and Zhang et al. (2013) use a grid or a rectangular moving window. Instead, we chose to use US Census Block Groups because they are intentionally delineated by the Census Bureau such that they contain between 600 and 3,000 people. While a block group certainly does not define an actual neighborhood, this characteristic ensures that each block group represents some functional urban space. Furthermore, block groups are the closest census aggregation unit to the optimal moving window size suggested by Zhang et al. (2013). The City of Phoenix is comprised of 977 block groups. Excluding 19 unusually large (larger than 11.5km^2) block groups which represented large conservation areas or unoccupied desert, block groups in this study range in size from 0.08km^2 to 11.3km^2, with a mean of 1.02km^2 and standard deviation of 1.20km^2 (N = 958). Our study calculates landscape metrics for all block groups and does not rely on random sampling.

Reliable data on buildings and structures for the city of Phoenix are available from the Maricopa County Assessor's Office and were cross-checked with the Maricopa Association of Governments, a regional planning body. These data record the construction year of the buildings on each land parcel as of 2012. In order to identify the historical time period during which development in a block group began to resemble its present-day form, we describe each block group using the decade by which half of the present-day structures had been built. While some buildings in Phoenix date back to the 1880s, the oldest block group using this classification technique is actually from the 1920s (Figure 3.1). However, only one block group is dominated by 1920s construction, two are dominated by 2010s construction, and nine block groups date principally from the 1930s. In contrast, defining historical zones by the age of the oldest building in an area, or by the time period during which the most construction occurred is less consistent with the path-dependent nature of development. Our goal is to identify when a sub-metropolitan area became "substantially developed" relative to its present-day land cover characteristics.

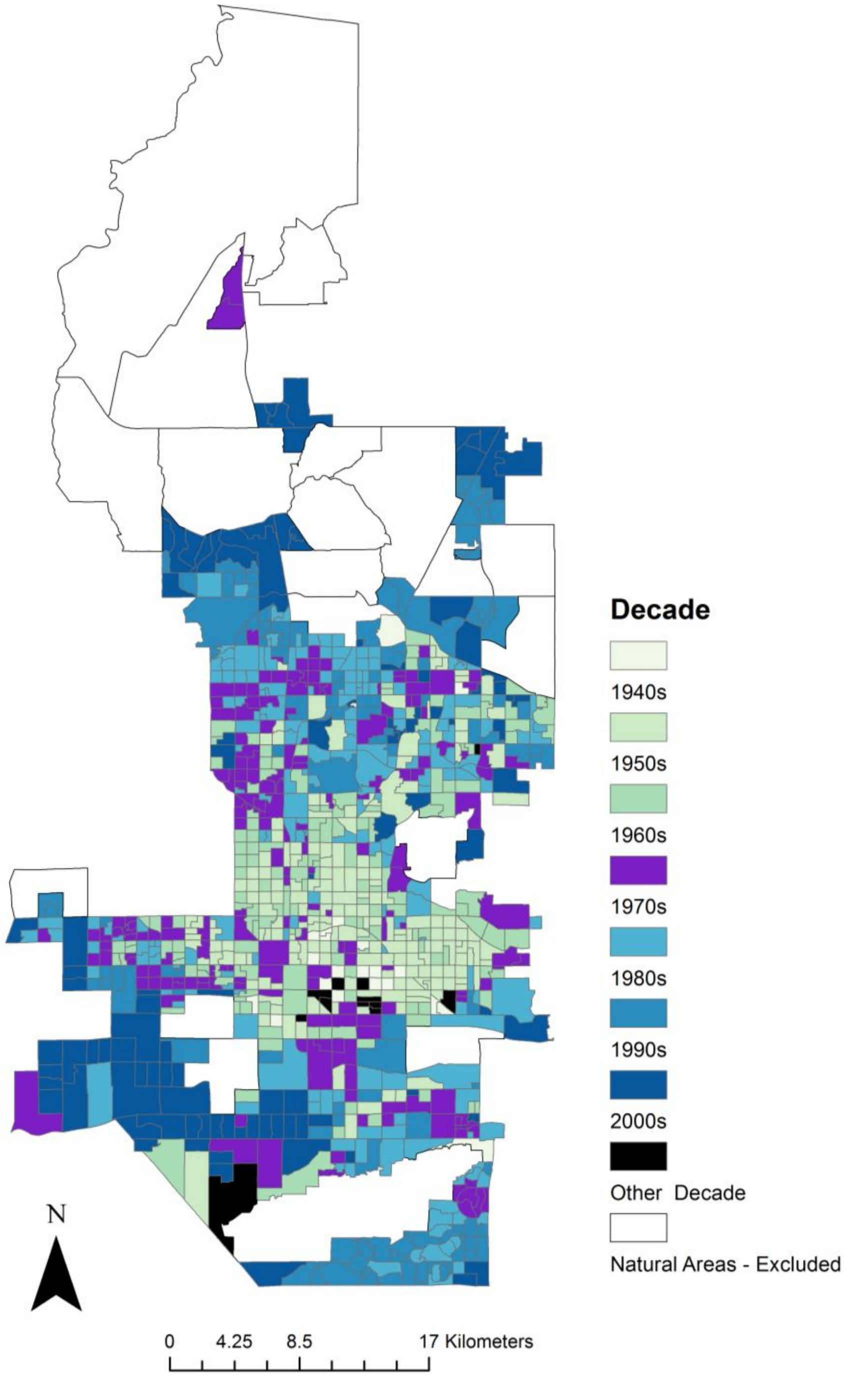

Figure 3.1: Phoenix block groups by dominant construction decade

This study compares present-day land cover characteristics (2010) with the age of the present-day building stock, as described above. In general, development in Phoenix is continually characterized by a desire for new construction in new areas (Gober 2006). Infill development is comparatively rare: buildings are not often knocked down, which makes this method of using public records from 2012 to identify historical zones a reasonably accurate indicator of when an area was originally developed.

3.2.3 Image Classification

The satellite images were classified using object-based image analysis (OBIA) and classification methods. OBIA methods are increasingly favored for the classification of high-resolution images because they can take advantage of the spatial and contextual information present at finer scales (Benz et al. 2004, Blaschke 2010). OBIA methods have two stages: segmentation and classification. Image segmentation involves grouping adjacent pixels with similar values into objects (Baatz and Schape 2000). Once formed, objects may then be assigned various values based on spectral and spatial properties calculated from all of the encapsulated pixels (e.g. averaging the reflectance of all pixels in the object). Objects are then assigned to discrete land cover classes using decision-based rule sets or automated algorithms. A set of decision-based rules is then used to classify the objects. Seven land cover classes were extracted from the classified NAIP image: buildings, roads, trees, grass, soil, shrubs, and croplands. After the classification, the results were inspected and obvious errors were manually corrected. Using this approach, we were able to achieve 91.86% accuracy (Li et al. 2014).

The decision to use these seven land cover classes (buildings, roads, trees, grass, soil, shrubs, and cropland) is based on changing development patterns in Phoenix and previous studies (e.g. Myint et al. 2013). These land cover classes were chosen to capture the heterogeneity of urban parcels in Phoenix, particularly the variation in residential landscaping. This finer thematic resolution, identifying land covers beyond the urbanized-nonurbanized dichotomy, provides the ability to examine detailed patterns in urban form and development. The land cover scheme includes some land covers that are natural to the American Southwest, such as desert soil and shrubs, but these features were largely replaced by turf lawns and non-native vegetation during earlier development periods (particularly in the 1960's and 1970's). New trends in development, however, have encouraged so-called xeric landscaping, which changes the land cover in residential areas from what would have been turf grass and trees to something that might mimic natural desert, such as soils. Because cropland and shrub classes represented only a very small proportion of the total land area within the Phoenix city limits, we excluded them from our subsequent statistical analyses.

3.2.4 Subset Images

Analysis is conducted at the block group level to provide an approximation of neighborhood areas, and in order to facilitate future comparison to census data. Using an automated process in a Python code 958 image subsets were extracted each conforming to the boundary of one census block group. In other words, using the boundaries of each individual block group in the City of Phoenix, the classified image was clipped to create 958 separate images for analysis. To illustrate this process, Figure 3.2 shows a selection of these subset land cover images for six different block groups from different historical zones.

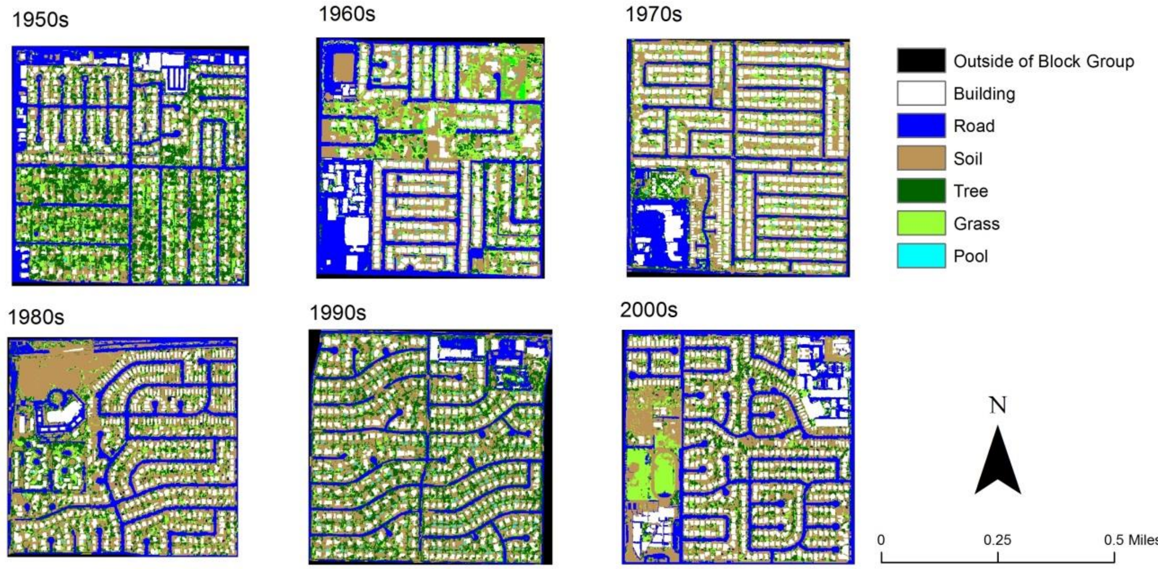

Figure 3.2: Samples of block group land cover by decade. These examples show subsets of our image, depicting the land cover for six different block groups. For illustration purposes, we selected images from different historical zones, although these may not be representative of all block groups in each given historical zone.

3.2.5 Spatial Metrics

In order to characterize the spatial pattern within each block group, spatial metrics are calculated for each of the 958 images using the FRAGSTATS package (McGarigal and Marks 1994). FRAGSTATS calculates three types of spatial metrics. Patch metrics are measures assigned to each individual patch, or contiguous area of a single land cover type. Class metrics provide a measure of spatial structure for all patches of the same class within the image – for example, the proportional area of tree cover for the entire census block group would be a class metric. Landscape metrics incorporate all patches of all land cover classes, for example to measure diversity or interspersion. This analysis calculates class and landscape metrics.

Schneider and Woodcock (2008) identified four urban growth indicators: size of built-up area and rate of change, density of built-up land, fragmentation, and population density. Whereas they conducted an interurban analysis, this study is concerned with intraurban characteristics and therefore modifies this framework to suit the higher spatial and thematic resolution of our one-city analysis. Rather than looking at size and density of built up areas, we consider the size and density of each land cover class because we are concerned with variation within built-up areas. Similarly, we consider the fragmentation of each land cover type rather than fragmentation of non-built up areas en masse. Following Herold, Liu and Clark (2003), who use 4-meter Ikonos imagery to analyze urban areas, we also investigate fractal dimension and contagion indices as measures of shape complexity. Interspersion and diversity are considered because these metrics are widely used to characterize fragmentation, particularly in studies of lower thematic resolution examining encroachment on non-urban lands. In sum, the selected metrics concern the 1) area and density of land covers 2) fragmentation/scatter, 3) shape complexity, and 4) diversity. These characteristics were selected because of their relevance to the broader definitions of urban sprawl, discussed above, and the specific metrics were selected because of their use in prior studies, thus facilitating comparison. The six landscape and five class metrics chosen are outlined in Table 3.1.

Metric	Level	Basic Description
Simpson's Diversity (SIDI)	Landscape	The square of the proportion of the landscape occupied by a patch type, summed over all patch types. In other words, the probability that any 2 randomly selected pixels would be of a different class.
Simpson's Evenness (SIEI)	Landscape	The Simpson's Diversity Index divided by the maximum possible Simpson's Diversity. It approaches zero when the landscape is dominated by a single class.
Contagion Index (CONTAG)	Landscape	A measure often used to determine the level of fragmentation between pixels. Contagion is high when a single class occupies a very large percentage of the landscape. It increases with an inequitable distribution of pairwise adjacencies.
Fractal Dimension (FRAC)	Landscape and Class	A measure of landscape complexity or fragmentation based on perimeter-to-area relationships. The area-weighted mean version is used.
Interspersion and Juxtaposition Index (IJI)	Landscape and Class	Measures the level of intermixing of patch types. The maximum value is achieved when all patch types are equally adjacent to all other patch types.
Patch Density (PD)	Landscape and Class	The number of patches in the landscape divided by the total area.
Percent of Landscape (PLAND)	Class	The percent of the total landscape represented by this class.
Contiguity Index (CONTIG)	Class	An assessment of the spatial connectedness (contiguity) of pixels based on a 3x3 pixel neighborhood. The area-weighted mean version is used.

Descriptions based on McGarigal and Marks (1994)

Table 3.1: Basic description of spatial metrics used

3.2.6 ANOVA

In order to analyze the differential impact of the timing of development on present-day land cover, we used Analysis of Variance (ANOVA) to identify statistically significant differences in spatial metrics between development periods. Tukey's HSD post-hoc test creates a confidence interval and significance value (p-value) for each pair of decades, using block groups as the unit of analysis. Since very few block groups became substantially developed (relative to their present-day form) prior to the 1940s or since the 2000s, we compare decades from the 1940s until the 2000s. Thus the statistical analysis is performed on a total of 946 block groups.

3.3 Results

Comparing the historical zones, the results reveal that more recently constructed areas differ in several ways from their older counterparts. In general, many landscape and class metrics appear to significantly vary based on the time periods during which areas were developed, which have in turn shaped variation in Phoenix's spatial structure. Many metrics, however, remain consistent across the different historical zones. Below, we discuss the specific differences in urban morphology among the historical areas.

The results of the ANOVA are presented in the form of cross-tabulation matrices. Each position within the matrix represents a comparison between two historical periods, and indicates whether the mean values were higher or lower in later construction periods compared to earlier construction periods. Each position also notes the statistical significance of the comparison through ANOVA post-hoc tests. Landscape metrics are presented in Table 3.2 and class metrics are shown for each individual land cover class in Table 3.3. Figure 3.3 also shows landscape metrics as boxplots, which display the variation in each landscape metric by development decade. The percent of the total landscape occupied by each class is shown as a stacked bar plot in Figure 3.4. These results are discussed in detail below.

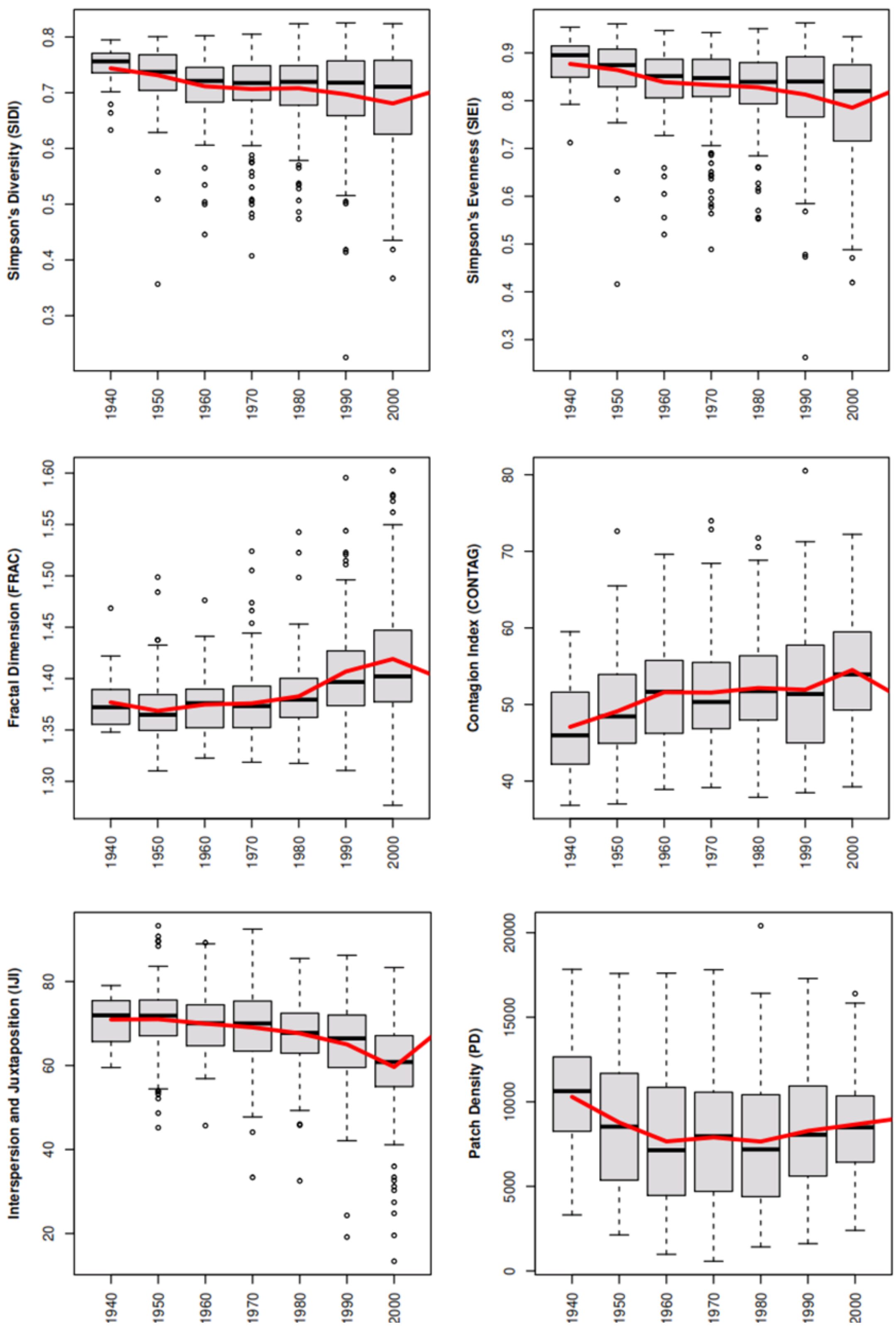

Figure 3.3: Boxplots of landscape-level metrics. The trend line connects mean values.

SIMPSON'S DIVERSITY

SIDI	50	60	70	80	90	00
40	–	–	–	–	–	–**
50		–	–*	–**	–**	–**
60			–	–	–	–*
70				+	–	–
80					–	–*
90						–

SIMPSON'S EVENNESS

SIEI	50	60	70	80	90	00
40	–	–	–	–	–*	–**
50		–	–*	–**	–**	–**
60			–	–	–	–**
70				–	–	–**
80					–	–**
90						–

FRACTAL DIMENSION

FRAC	50	60	70	80	90	00
40	–	–	–	+	+*	+**
50		+	+	+*	+**	+**
60			+	+	+**	+**
70				+	+**	+**
80					+**	+**
90						+

CONTAGION INDEX

CONTAG	50	60	70	80	90	00
40	+	+	+	+*	+	+**
50		+*	+*	+**	+*	+**
60			–	+	+	+*
70				+	+	+*
80					–	+
90						+

INTERSPERSION/JUXTAPOSITION

IJI	50	60	70	80	90	00
40	+	–	–	–	–	–**
50		–	–	–*	–**	–**
60			–	–	–**	–**
70				–	–**	–**
80					–	–**
90						–**

PATCH DENSITY

PD	50	60	70	80	90	00
40	–	–	–	–	–	–
50		–	–	–	–	–
60			+	–	+	+
70				–	+	+
80					+	+
90						+

Table 3.2: ANOVA pairwise post-hoc tests for landscape-level metrics *(*p < 0.05, **p < 0.01)* presented as a cross-tabulation matrix. Pluses and minuses indicate whether whether the metric's value is higher or lower in the subsequent (more recent) decade. Descriptions of landscape metrics can be found in Table 3.1.

3.3.1 Area and Density of Land Covers

Comparing the various historical zones, there is evidence of significant differences in the area and density of impervious features (buildings and roads). Buildings, in particular, show a notable decrease in their proportional cover (PLAND) across the historical zones as the construction data advances in time. The highest proportional area of buildings is found in block groups dominated by 1950s construction, occupying an average of approximately 19 percent of the total area. In contrast, the 2000s historical zone has an average proportional area of only 11 percent. The ANOVA results corroborate, indicating that this decrease was significant when comparing more recently constructed areas (1990s and 2000s) with areas built between the 1950s and 1980s. The same pattern is apparent for patch density (PD) of buildings, indicating a lower density of buildings in more recent construction zones as well. Similarly, the proportional area of roads is lower in the 1990s and 2000s block groups than in block groups constructed in earlier periods. Road density, however, is not discernibly different among the different periods.

Comparing the different historical periods, we also see notable differences in the proportional area and density of soil patches. The proportional area of soil remains fairly consistent across the historical zones, except for the 1990s and 2000s zones, which show slight increases in mean soil area. As indicated by the ANOVA results, the area of soil in the 2000s zone is significantly different from most of the areas of earlier construction (except the 1940s and 1990s zones). Patch density of soil, however, is highest for the 1940s and 1950s zones, and is significantly different from all zones dominated by later construction.

Although some differences in the area and density of tree and grass cover can be seen in the data, these differences were only significant when comparing areas built during the 1940s and 1950s to later construction periods. Specifically, 1950s zones have higher average tree cover than areas constructed in the 1970s, 1980s, and 2000s, but the patch density of trees is not significantly different among the other historical zones. The proportional area of grass is generally lower in more recently constructed areas, but as with trees, this difference is only significant when comparing recent construction to the 1940s and 1950s areas. The areas constructed in the 1940s and 1950s also have a higher density of grass patches than later-constructed periods. In sum, more recently constructed areas generally have less tree cover and less grass cover than their older counterparts.

3.3.2 Fragmentation and Scatter

The contagion index (CONTAG) provides a landscape-level measure of fragmentation, accounting for all land cover classes. The cross-tabulation matrix for the contagion index shows that the mean value for more recently constructed periods is almost always higher than preceding periods (with the exception of two points in the matrix). Newly constructed areas, thus, show greater fragmentation than older areas. Most notably, the 1950s had a significantly lower contagion than all later construction periods, and areas constructed in the 2000s have a significantly higher mean contagion than all areas built between the 1940s and 1970s. The interspersion and juxtaposition index (IJI) landscape-level metric (not to be mistaken for the IJI class-level metrics discussed later), which measures the overall intermixing of classes complements these results: there is significantly less intermixing in areas developed during the 1990s and 2000s.

In addition to these landscape metrics, class-level measures of interspersion (IJI) and contiguity (CONTIG) provide class-specific measurements of scatteredness, which can also be indicative of fragmentation. Specifically, IJI provides information on the relationship between different types of land covers and how frequently they come in contact with each other. This is indicative of landscape heterogeneity and the degree of segregation among land covers. Like its landscape-level counterpart, the IJI for each individual class also shows that the interspersion of land covers is significantly lower in more recently constructed areas.

The position of buildings relative to other land cover classes also differs significantly across the zones. This is reflected in the contiguity and class-level IJI indices: the 2000s historical zone differs significantly from most preceding periods. Thus, buildings in newer areas interface with fewer types of land covers. Roads, similarly, appear to interact with fewer types of land covers in areas of newer construction. The 2000s construction period, in particular has significantly lower IJI than past periods. Roads, in contrast, do not show significant differences in contiguity.

Soil patches also show a significantly lower IJI in areas developed during the 2000s, indicating less interspersion with other land covers, but show a higher level of contiguity in later periods. This difference in contiguity is significantly higher when comparing the 2000s zone to areas constructed in the 1950s and 1980s. In combination, these results suggest that later-constructed areas are characterized by continuous patches of soil that do not frequently intersect other land cover types. In contrast, tree covers, particularly in the 2000s, intersect less frequently with other use types but also are less contiguous, as indicated by the IJI and contiguity index, respectively. The IJI for grass cover is significantly lower in later-constructed areas across almost all pairs of decades though the contiguity index shows no significant patterns – that is to say, while grass patches in newer developing areas are no more or less fragmented, they consistently interface less with other land covers.

3.3.3 Shape Complexity

The fractal dimension (FRAC) index is commonly used in studies of sprawl or fragmentation of urban areas (see, e.g., Herold et al. 2005), as it provides additional information about the complexity of land cover features. Specifically, the fractal dimension index provides a measure of the departure from Euclidean geometry, or straight-line edges. For the study area, this index is consistently higher in newer-developed areas. Considering the fractal dimension for all patches (i.e. landscape-level metric), landscape shapes appear more complex in more recently developed regions, with a significantly higher mean fractal dimension index in areas developed during the 1990s and 2000s.

Differences in shape complexity are also apparent for specific land cover classes across the various historical areas. In particular, tree and soil patches show much higher complexity in newer areas of the city. For trees, the fractal dimension in the 2000s zone is significantly different from areas constructed in the 1950s, 1960s, and 1970s. For soils, the fractal dimension index increases incrementally across the different historical zones, with the lowest value in the 1940s and the highest in 2000s – the mean values for the 1990s and 2000s zones are significantly different from the block groups in the preceding periods.

3.3.4 Diversity

Simpson’s Diversity index (SIDI) indicates that areas developed in the 1950s have significantly higher diversity than newer areas, while areas that developed in the 2000s show significantly lower landscape diversity than older ones. This indicates a more homogenous landscape in newer areas. Simpson’s evenness index (SIEI), which approaches zero when the landscape is dominated by a single class, shows the same pattern: while newer areas have continually lower evenness, differences are statistically significant when comparing the 1950s to subsequent decades (block groups developed during the 1950s have much higher evenness), and when comparing the 2000s to previous decades (the most recently developed block groups have much lower evenness than older areas).

BUILDINGS

PLAND	50	60	70	80	90	00
40	+	+	+	+	–	–
50		–	–	–	–**	–**
60			–	–	–**	–**
70				–	–**	–**
80					–**	–**
90						–

PD	50	60	70	80	90	00
40	–	–	–	–	–*	–**
50		–	–	–*	–**	–**
60			–	–	–**	–**
70				–	–**	–**
80					–*	–**
90						–

IJI	50	60	70	80	90	00
40	–	–	–*	–*	–*	–**
50		–	–*	–*	–**	–**
60			–	–	–	–**
70				+	–	–**
80					–	–**
90						–

CONTIG	50	60	70	80	90	00
40	+	+	+*	+	+	–
50		+	+	–	–	–*
60			+	–	–	–**
70				–	–	–**
80					–	–
90						–

FRAC	50	60	70	80	90	00
40	–	+	+	+	+	–
50		+	+	+**	+	+
60			–	+	+	–
70				+	–	–
80					–	–
90						–

SOIL

PLAND	50	60	70	80	90	00
40	+	+	+	+	+	+
50		–	–	–	+	+*
60			–	–	+	+**
70				–	+	+**
80					+	+**
90						+

PD	50	60	70	80	90	00
40	–	–*	–**	–*	–**	–*
50		–**	–**	–**	–**	–*
60			–	+	–	+
70				+	–	+
80					–	–
90						+

IJI	50	60	70	80	90	00
40	+	+	+	–	–	–
50		–	–	–**	–	–**
60			–	–*	–	–**
70				–	–	–**
80					+	–**
90						–**

CONTIG	50	60	70	80	90	00
40	+	+	+	+	+	+
50		+	+	+	+	+**
60			–	–	+	+
70				–	+	+
80					+	+*
90						+

FRAC	50	60	70	80	90	00
40	+	+	+	+	+**	+**
50		+	+	+	+**	+**
60			+	+	+**	+**
70				+	+**	+**
80					+**	+**
90						+

TREE

PLAND	50	60	70	80	90	00
40	–	–	–	–	–	–
50		–	–*	–**	–	–**
60			–	+	+	–
70				+	+	–
80					–	–
90						–

PD	50	60	70	80	90	00
40	–	–	–	–	–	–
50		–	+	–	–	–
60			+	–	–	–
70				–	–	–
80					–	+
90						+

IJI	50	60	70	80	90	00
40	–	–	–	–	–	–**
50		–	–	–	–**	–**
60			–	–	–	–**
70				–	–	–**
80					–	–**
90						–

CONTIG	50	60	70	80	90	00
40	+	–	–	+	+	–
50		–	–*	+	+	–**
60			–	+	+	–**
70				+**	+	–**
80					–	–**
90						–**

FRAC	50	60	70	80	90	00
40	–	–	–	–	+	+
50		–	+	+	+	+*
60			+	+	+	+**
70				+	+	+*
80					+	+
90						+

GRASS

PLAND	50	60	70	80	90	00
40	–	–**	–*	–*	–**	–**
50		–*	–	–	–**	–**
60			+	+	–	–
70				+	–	–
80					–	–
90						–

PD	50	60	70	80	90	00
40	–	–*	–*	–*	–*	–**
50		–	–	–	–	–**
60			+	–	–	–
70				–	–	–
80					–	–
90						–

IJI	50	60	70	80	90	00
40	+	+	–	–	–	–**
50		–	–**	–**	–**	–**
60			–**	–**	–**	–**
70				–	–**	–**
80					–	–**
90						–**

CONTIG	50	60	70	80	90	00
40	+	+	+	+	+	+
50		–	+	+	+	+
60			+	+	+	+
70				+	+	+
80					+	–
90						–

FRAC	50	60	70	80	90	00
40	–	–	–	–	–	–
50		–	+	+	+	+
60			+	+	+	+
70				–	+	+
80					–	+
90						+

ROADS

PLAND	50	60	70	80	90	00
40	+	+	+	+	–	–
50		+	–	–	–**	–**
60			–	–	–**	–**
70				–	–**	–**
80					–**	–**
90						–

PD	50	60	70	80	90	00
40	–	–	–	–	–	–
50		–	–	–	–	–
60			+	+	–	–
70				+	+	–
80					+	–
90						–

IJI	50	60	70	80	90	00
40	–	–	–	–	–	–**
50		–	–	–	–**	–**
60			–	–	–*	–**
70				–	–	–**
80					–	–**
90						–

CONTIG	50	60	70	80	90	00
40	+	+	+	+	+	+
50		+	+	+	–	–
60			+	–	–	–*
70				–	–*	–**
80					–	–
90						–

FRAC	50	60	70	80	90	00
40	+	+	–	–	+	+
50		–	–**	–*	–	–
60			–	–	+	+
70				+	+	+
80					+	+
90						+

Table 3.3: ANOVA pairwise post-hoc tests for class-level metrics *(*p < 0.05, **p < 0.01)* presented as a cross-tabulation matrix. Pluses and minuses indicate whether the metric's value is higher or lower in the subsequent (more recent) decade. Descriptions of class metrics can be found in Table 3.1.

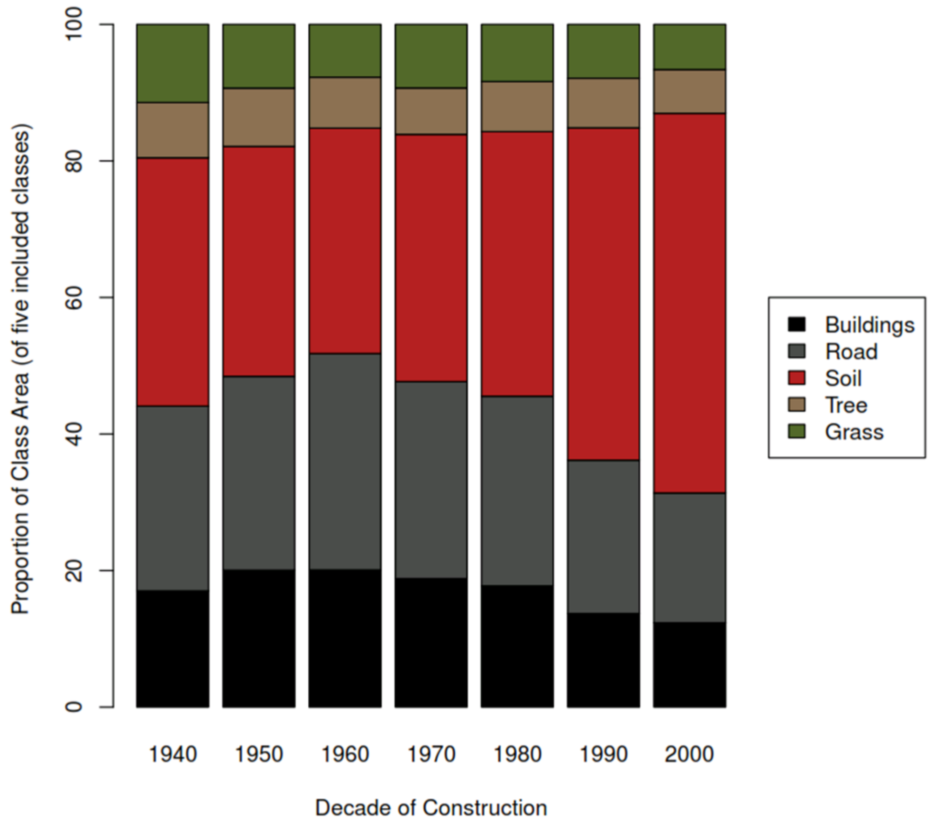

Figure 3.4: Percent of identified landscape cover occupied by each class, by construction decade (cropland and shrub classes not included).

3.4 Discussion

First, our results confirm that there is substantial variation in present-day land cover characteristics in sub-metropolitan areas based on dominant periods of development, supporting the hypothesis about path-dependence with respect to landscape structure. For many class-level and landscape-level metrics, block groups that developed principally during the 1990s and 2000s displayed significantly different values from earlier-developing regions. These areas tend to differ most significantly from areas that developed during the 1950s.

By analyzing sprawl across four distinct dimensions (area and density of land cover, fragmentation/scatter, shape complexity, and diversity), we are able to expand upon previous studies such as Irwin and Bockstael (2007), Shrestha et al. (2012), and Zhang et al. (2013). Those studies, using 30m data (which is more adept at detecting variation between parcels of land), have generally corroborated the traditional conceptualization of urban sprawl by providing evidence of increased fragmentation near the urban fringe. Comparison with these studies is complicated by the fact that our results involve more land cover classes and higher resolution; however, newer-developing areas in our study do appear more fragmented. Furthermore, landscape patches interface less frequently with different land cover classes, suggesting that newer-developing areas are actually more homogenous when we consider several types of land cover (buildings, roads, trees, grass, soil, shrub, and cropland). While it is not surprising that newer areas are also less diverse and are covered with fewer roads and buildings, the within-lot land cover classification that our high-resolution data affords also provides evidence of a shift from grass and tree covers to soil cover. Shape complexity appears higher in newer areas as well.

We speculate that certain institutional and economic changes in land use during the 1990s and 2000s explain some of our results. During the 1960s, commercial uses fled the downtown area in favor of decentralized office parks, shopping malls, and strip retail along arterial streets (Luckingham 1989), resulting in a different style of business land use that not only has a larger footprint but more within-lot variation: shade trees, buildings, grass, and parking may depart more from Euclidean geometry than in a rectilinear downtown streetscape. Zoning and city ordinances also transformed residential areas during the latter half of the twentieth century. Increasing minimum lot sizes for residentially-zoned land, a trend that took place over this period in the Phoenix area and nationwide (Talen 2012, Fischel 2001) could result in increasing shape complexity within individual lots, especially when compared to a cookie-cutter 1950s-era ranch home. Atkinson-Palombo (2010) found that a wider variety of housing types were present at the urban fringe during the 2000s, which also corroborates some of our results: a wider variety of building styles could result in increased shape complexity in this category, while a higher proportion of multifamily housing would result in smaller building footprints and a lower percent landscape for buildings despite growth in the number of housing units. Newer construction is also more likely to abut agricultural lands, which may account for differences in proportional cover as well. In Phoenix, water rights could play a particularly important role in shaping the extent and pattern of land cover. Water rights are attached to a particular property and affect the types of irrigation permitted and cost of water associated with a particular property.

In addition to institutional and economic changes, the development style and preferences of residents living in Phoenix may also explain why the 1990s and 2000s zones appear distinctly different. The CBD influenced much of the early development of Phoenix and still has a great influence on the land use history (Keys et al. 2007). This could account for similar configurations seen up until the 1990s zones. However, it does not account for why the 1990s and 2000s zones change so distinctly, particularly in terms of fragmentation and shape complexity. Further observations show that the development style in Phoenix changes with time. Leapfrog development was a large part of residential development in American cities between the 1950s and 2000s, particularly in Phoenix (Helm 2001, Carruthers 2003). This created patches of undeveloped land parcels that were filled in during later development periods, but it was not until after 1970 that leapfrogging in Phoenix occurred at greater distances from the CBD (Helm 2001). Based on our observations, all of these factors are likely to manifest themselves in the configuration of the 1990s and 2000s zones, where a number of metrics become significantly different.

Finally, previous research has shown that natives of the Phoenix area seem to prefer mesic, or grassier, landscaping in backyards in contrast to more recent migrants who moved to the desert area in droves throughout the second half of the twentieth century. In addition, preferences for landscaping in Phoenix generally tend to exhibit a "legacy effect" wherein historically mesic landscape patterns persist in older areas (Larson et al. 2009). Grass covers are at their highest in the 1940s and 1950s zones. Grass patch density is highest in the 1940s zone and grass patches less likely to be near other cover types in newer areas. This may indicate that grasses that do exist in newer-developing areas are in large open spaces such as parks or golf courses, where patches are larger and less mixed-in with other land cover types. In contrast, newer areas feature more soil cover, it is less dense, and its shape complexity is higher, suggesting that desert-like land cover is more prevalent in backyards than larger public or undeveloped areas.

3.5 Conclusions

Land cover in urban areas is much more complex than the typical sprawl narrative of increasing fragmentation as one travels toward the urban fringe. The metropolis has long since ceased to be a monocentric entity; analysis of areas because of some particular characteristic may be better understood by delineating areas by when they were developed instead of based on their proximity to the urban core. Results confirm that sub-metropolitan areas developing principally in different time periods have different present-day land cover characteristics. Legacy effects and historical development trends are important to understanding present-day landscape function and ecosystem services. While evidence suggests that newly-developed areas of Phoenix are less diverse, more homogenous, and more fragmented, this higher-resolution approach goes beyond these traditional narratives, finding significant increases in shape complexity and differing preferences for landscaping in newer-developing areas. Generally speaking, though, these results corroborate prior research (e.g., Atkinson-Palombo 2010) which has suggested that the most recent wave of development (1990s and onward) in Phoenix and elsewhere was distinct from past forms of urban development.

Resolution, both spatial and thematic, remains a very important consideration in analyzing what constitutes urban sprawl, especially given the increase in data and spatial analysis tools available. While an ecological understanding of landscape complexity and arrangement at the 1-m level is not yet as developed owing to the newness of such data, urbanization and the realization of the importance of urban areas to environmental outcomes suggest that this is a key area of future research (Turner et al., 2013). The definition of "fragmentation," for example, changes whether the research involves only individual lots, or whether it considers individual trees, sidewalks, and lawn patches. It also changes whether analysis concerns a simple developed/undeveloped dichotomy, or is attempting to observe more nuanced aspects of urban pattern. The scale of the aggregation unit merits careful consideration as well. The choice of block groups as units of analysis was guided principally by theory: it makes sense in Phoenix for analyzing sub-metropolitan areas that are experienced by individuals, but a different aggregation unit may make more sense for different levels of spatial or thematic resolution, or if comparing between different cities. A future study exploring the sensitivity of results to changes in aggregation units would increase the utility of newly-available high-resolution data.

While much of our discussion linking landscape change to specific institutional, economic, and behavioral drivers remains speculative, the approach of linking fine-resolution land cover to development periods removes the assumption of monocentricity that is implicit in urban gradient studies and helps to avoid overlooking infill and leapfrog development patterns. A next step beyond using aggregated information from FRAGSTATS spatial metrics could use high-resolution land cover classifications to identify a typology of building and development styles (e.g., ¼-acre lot ranch homes versus McMansions; strip retail versus mega-malls). Further, an explicit link to ecological outcomes, such as hydrology or urban heat island, could also move the discussion toward whether and why certain types of development may be better or worse. This information and similar analysis can support urban planning in Phoenix and elsewhere. By analyzing spatial and temporal pattern variation, it is possible to evaluate the impacts of land use institutions and changing development trends on the overall urban landscape. Nonetheless, greater understanding of the relationship between pattern and landscape ecology is required to assess the environmental implications of development types and institutional arrangements. By highlighting spatial pattern differences across Phoenix, this research hopes to move the discussion of urban landscape pattern beyond identifying homogeneity and fragmentation and toward an analysis of what it means and whether it matters.

CHAPTER 4

RESIDENTIAL DEVELOPMENT DURING THE GREAT RECESSION

4.1 Introduction

The Real Estate collapse has had a lasting effect on global financial markets, but these effects have varied across localities. Critical perspectives demonstrate how place-bound, local financial decision-making – mortgage debt instruments – precipitated a global financial crisis through the broad redistribution and repackaging of local mortgage debt via complex financial derivatives (Aalbers 2009, Martin 2010, Crump et al. 2013). In turn there may be reciprocal effects of the global financial crisis on local development preferences and patterns. Foreclosure studies provide an early indicator of which neighborhoods were hit the hardest (Immergluck 2010), but have changes in global capital availability begun to transform housing choice, and consequently, urban morphology? Urban theorists have long claimed that "the way people want to live is more richly varied than post-war suburban planners had imagined," emphasizing that zoning and developer behavior have constricted the choice of available housing: fringe development is not "the product solely of market forces" (Levine 1998). Popular accounts following the sub-prime collapse proclaim the "death of exurbia" – that the forces promoting inexpensive, homogenous, car-dependent fringe suburbs are gone and true preferences for more mixed urbanism – revealed in surveys but not in behavior due to the limited stock of different housing types – can now be fulfilled (Leinberger 2011). Developers may respond by reimagining the style and location of housing they supply in response to changing demographics and individual demands.

Now, several years after the housing collapse, it is possible to study the locus of new housing development to search for evidence of the beginnings of a structural shift. Analyses of the recession emphasize the role of institutions in its cause and its outcomes: federal mortgage deregulation and increased mortgage securitization led to the crisis, while state-specific foreclosure laws affected its impact on neighborhoods. Local zoning often shapes land use (Talen 2012), but the manner in which zoning affects development decisions during boom-and-bust cycles has not been examined. In other words, has the recession altered individuals' preferences for housing, the impact of local regulations on development decisions, and the manner in which developers supply single family housing?

This study analyzes the city of Phoenix, Arizona, considered a poster child for urban sprawl (Gober 2006). The city has a long history of booms, busts, and speculative development (VanderMeer 2002), in addition to an oppressive desert heat that is continually worsened by development (see, e.g., Ross 2011). Home prices in the Phoenix area more than doubled from 2000 to 2006, typical of a fast-growing Sunbelt city. The region was a hotbed for sub-prime mortgages, with a particularly high concentration of these in lower-income neighborhoods (Agarwal et al. 2012). Due to Phoenix's aggressive land annexation policies, the municipality's density gradient is similar to the gradient of the metropolitan area as a whole and includes a historic core alongside suburban-style single family homes, agricultural lands, and undeveloped desert (Heim 2012). This analysis is restricted to single family homes, the quintessential suburban development, to determine how drivers of residential development changed between the booming real estate years of 2002-2006 and the subsequent collapse over 2006-2012.

This study uses theory from economic geography and a logistic regression at the parcel-level to empirically analyze these perspectives about residential development and land use trajectories during the recession. We begin with the tradeoff between access and space (in the tradition of, e.g., Park, Burgess, McKenzie, & Wirth 1925, Alonso 1964). A variety of perspectives have stressed the importance of the immediate neighborhood as a determinant of social outcomes (Sampson 2013), a component of gentrifying cities (Smith 1996), and as an indicator of walkability and smart growth (Talen 2011), thus we include counts of parcels by use type within a potential development site's immediate vicinity. Zoning is included as it is thought to constrain development decisions by increasing costs and delaying building. Results provide empirical support for claims about the changing locus of development resulting from the recession, while the analytical framework, drawing from traditions in urban economic geography, provides a fine-grained method for analyzing urban development patterns.

4.2 Literature and Background

4.2.1 The Great Recession

Phoenix has long been known for its booms, busts, and rapidly changing urban morphology (York et al. 2011a, Kane et al. 2014b). Atkinson-Palombo (2010) notes that development styles and urban form in Phoenix vary across time periods, finding evidence of increased density along the urban fringe in the early 2000s which contrasted with the rapid outward push of single family homes experienced during the nineties. Federal Reserve data indicate that Arizona housing starts in 2002 increased 15.04% over the previous year, a trend that continued until 2005, while in 2006 housing starts decreased by 29.64%. They continued to decrease every year until 2012 (Table 4.1).

Year	Housing Starts	Percent Change
1999	51,915	n.a.
2000	47,415	-8.67%
2001	47,719	0.64%
2002	54,894	15.04%
2003	63,388	15.47%
2004	76,651	20.92%
2005	78,006	1.77%
2006	54,882	-29.64%
2007	36,796	-32.95%
2008	17,687	-51.93%
2009	12,835	-27.43%
2010	10,972	-14.51%
2011	10,637	-3.05%
2012	16,023	50.63%

Source: *Federal Reserve Bank of St. Louis*

Table 4.1: Housing starts, state of Arizona

Phoenix's spectacular booms and busts do not happen in a vacuum – urban geographers have highlighted the local-global connection of the most recent housing collapse and recession. Aalbers (2009) describes how a crisis in local housing markets became a crisis in the global mortgage market. This upscaling, he argues, was the result of deregulation and the creation of a secondary mortgage market, which allowed agents to profit from globalizing and financializing a local product. Martin (2010) proposes that the hyper-fungibility of capital has micro- and macro-geographic impacts, showing that impacts of the housing collapse were not nationally uniform; instead, they varied between cities that had "cyclical markets," "steady markets," or those characterized as "recent boomers," the last of which experienced the highest foreclosure rates. Immergluck

(2010) explores the micro-geographical dimension of foreclosures, finding higher rates in newer and faster-growing ZIP codes, though he was not able to establish a clear connection between intrametropolitan location and foreclosures specifically, i.e. fringe development is not clearly implicated in the crisis; if anything, inner cities had higher rates of bank-owned property. Crump et al. (2013) showcase related equity concerns: once-redlined neighborhoods became profitable places for subprime mortgages and subsequently became foreclosure hotspots. For many urban scholars, this recession's housing crisis is a symptom of a much deeper and yet unresolved urban crisis, with the "Growth Machine's" (Molotch 1976) exclusion mechanisms exhibiting some vulnerability (Schafran 2013, Harvey 2009). Though this study's explicit focus is on land use outcomes rather than the social dimensions of the crisis, critical perspectives provide useful hypotheses about supply and choice to examine empirically.

The crisis has also been studied by land use economists: Lee (2011) models the spillover effects of foreclosures on the prices of nearby homes and Cho, Kim and Roberts (2011) construct a hedonic pricing model to show that the value of environmental amenities in Nashville, Tennessee decreased slightly following the real estate collapse. The latter study found an increased preference for housing near the downtown area following the bust, which the authors hypothesize might be the result of decreased mobility and disposable income associated with the recession. Finally, some have pointed out that the recession appears to coincide with demographic trends favoring walkable, downtown neighborhoods, preferred by the increasing population of empty-nesters and childless adults (Plane 2013). This suggests a re-evaluation of the type of housing supplied by developers, despite the historically lower risk and ease of underwriting suburban tract homes (Leinberger and Alfonzo 2012).

4.2.2 Housing supply: Developers and zoning

Urban planners have long claimed that sprawl is the inefficient outcome of an unregulated market economy (Bruegmann 2005, Whyte 1958). Undifferentiated, single family housing at the urban fringe is less risky, cheaper to finance (Leinberger and Alfonzo 2012), and is a standardized product that is easier to produce and absorb in the market (Peiser 2001). A market failure explanation is often invoked to explain why a demand for denser urban dwellings may exist but is not realized (Brueckner 2000). In short, individual choice is often circumscribed by the decisions of developers.

Developers themselves may also be constrained by municipal zoning, which can restrict available sites or require a costly and time-consuming rezoning process. American zoning is typically based on a so-called “Euclidean” hierarchy of segregated land uses, with single family residential areas having very restrictive rules about permitted uses, followed by higher-density housing, commercial, and finally industrial land uses that are often lax and allow most higher order uses (Hall 2007). Zoning is generally treated as an institutional constraint on landowners (Nelson 1977, White 1978, Fischel 2010). Levine (1998) views land use regulations as constraints on choice which have for decades “shackled housing markets and ensured standardized outcomes.”

On the other hand, land use outcomes are not necessarily the same as predicted or intended. Talen (2012) notes the indirectness of the effect of building regulations on urban form, suggesting that “the effects are known in general terms, on such things as density and land value, but the effect on physical form and character of place is often obscured," while Carruthers (2003) argues that the limited nature of zoning and inconsistent policies across nearby municipalities drive exurbanization and land use fragmentation. Empirical findings have found that zoning may have a variety of effects. Glaeser and Gyourko (2002) demonstrate that zoning is partially to blame for the decreased availability of affordable housing, particularly near increasingly suburban employment centers, while others have emphasized that zoning's role in landscape fragmentation and the protection of natural areas (York and Munroe 2010, Munroe, Croissant and York 2005).

Because of this, zoning and developer behavior are thought to constrain housing supply such that it is not perfectly reflective of individual home buyers' demand. Critical perspectives suggest that individuals do not have as much variety in housing choice as they would like while developers are free to manipulate zoning through variances and re-zonings; thus zoning and development are both reflective of developer preferences (York, Feiock and Steinacker 2013, Molotch 1979). On the other hand, developers may actually be constrained by existing homeowners: Fischel (2001) argues that municipal zoning primarily reflects local homeowners' interest in protecting the value of their property. While developers may have some entrepreneurial agency, zoning is likely to pose at least a procedural inconvenience. Zoning is a major component of where a developer builds a particular piece of property, though ultimately the decision to develop land is based on a financial analysis, which would include the cost of any uncertainty or time delays associated with an unfavorable zoning designation (Reed and Sims 2008).

Preferences revealed through housing choice reflect the interplay of both supply and demand. At best, they indirectly reflect individual choice, as developers must be sensitive to changing demand for housing, e.g. a reduced preference for fringe development must eventually result in an increased supply of denser, more centrally-located homes if nobody were interested in buying the former and they became unprofitable to supply. In this way, developers must be sensitive to the preferences of individuals as well as to institutional constraints in order to convert their effort (which includes, if needed, securing a zoning variance) into return on investment. However, an individual homebuyer is probably not directly concerned with the price the developer paid for the land or its original zoning designation.

4.2.3 Housing Demand: Individuals and Place

The aim of this paper is to investigate the changing locus of single family housing development in Phoenix during the recession. While land prices and zoning may constrain the quantity and location of housing supplied by a developer, individuals' preferences for place also have a role in determining where development will take place. The traditional urban economic model of residential location is based on a tradeoff between access and space which is little more than a comparison between commuting time and the size of a home. The decreasing importance of physical distance to fulfill certain needs (e.g., telecommuting and online shopping), the substitution of square footage for other forms of consumption such as nearby amenities, and choice of location based on status all hint at an evolution of preferences beyond this strict dichotomy (Phe and Wakely 2000). New Urbanists address the social and environmental ills of 20th century development patterns by emphasizing more compact, sustainable cities with complementary nearby uses (Talen 2012), while sociologists stress that the "neighborhood matters" for the reproduction of poverty and education levels across generations (Sampson 2013). Empirically, Carrion-Flores and Irwin (2004) show that the composition of the immediate neighborhood has a strong spillover effect on the likelihood of residential development, which they find to be more likely in close proximity to existing residential or commercial uses.

Urban theorists and critical geographers claiming that there is an oversupply of suburbia and limited choice in housing type may see the recession as a harbinger of urban inversion: we may soon witness the "death of the fringe" (Leinberger 2011) or the advent of "slumburbia" (Schafran 2013). Methods for better understanding these phenomena might include extensive surveying of stakeholders and decision makers, or descriptive analyses of select properties or areas. Most empirical approaches toward residential location involve aggregate geographies such as census tracts (Li, Campbell and Fernandez 2013), ZIP codes (Immergluck 2010), or even municipalities (Bunel and Tovar 2013), though results can be highly sensitive to the choice of spatial units. Spatial representation must follow the data-generating process and urban land use decisions are made at the parcel level. By directly linking the unit of observation with the decision-maker, the behavioral component of land-use change can be isolated and used to reconcile theoretical drivers (processes) with spatially-explicit outcomes (patterns) (Bell and Irwin 2002, Irwin 2010).

4.3 Empirical Setting

The existing theoretical and empirical literature has demonstrated how aspects of supply and demand for single family residences may have changed during the recession. While the distinction between a developer's criteria for supplying housing and an individual's criteria for demanding housing is somewhat artificial, this dichotomy provides a useful starting point for our empirical work. Since developers are thought to be more sensitive to land cost and institutional setting, our developer/supply model includes the parcel's land value in the base year, the land value of surrounding parcels as a measure of neighborhood wealth, the parcel's land use type in the base year, and its zoning designation prior to conversion. Individuals are thought to be more sensitive to the amenities and place-sensitive characteristics of a potential home, so the individual/demand model includes population density, the parcel's distance to the center of the downtown (CBD), the distance to the nearest of the region's six edge cities or subcenters (Garreau 1991, Leslie and Ó hUallacháin 2006), whether it is in walking distance to Phoenix's lone light rail line (approved in 2000 and opened in 2008), and its proximity to other parcels of complementary or incompatible use types. Since Phoenix has a history of exclusionary housing practices and certain neighborhoods may still be considered "stigmatized" based on race (Bolin et al. 2005), we also include an area's percent White, non-Hispanic. This may affect both a developer's decision to invest in housing as well as an individual's decision to live in an area; we include it in the individual/demand model so that it is considered alongside other census-derived variables.

4.3.1 Model specification

This model will determine the probability that a given parcel P^1 will convert from initial land use i to final land use SFR (single family residential) in the final year conditional on its base year characteristics:

$$Pr(P_i^1 \rightarrow P_{SFR}^1 \big| \; X_d^1 \quad X_s^1)$$

where X_d^1 is a *1 x k* vector of base year parcel characteristics most relevant to an individual's demand for housing and X_s^1 is a *1 x k* vector of base year parcel characteristics most relevant to a developer's willingness to supply housing. A logistic regression is used to model a binary response variable: in this case, the log of the odds of whether a parcel experiences a conversion to a single-family residence:

$$Log\,\frac{Pr}{1-Pr} = \propto + \beta_D X_D + \ \beta_S X_S + \varepsilon$$

where the capital *X*'s are *n x k* matrices of the aforementioned vectors, expanded in the *n* direction by the number of parcels in Phoenix. Results are reported as odds ratios:

$$\frac{\widehat{Pr_\iota}}{1-\ \widehat{Pr_\iota}} = \ e^{\alpha} + \ e^{\beta_1 X_1} + \cdots + \ e^{\beta_k X_k}$$

which indicate the likelihood of development based on a given characteristic. An odds ratio of 1.5 on a binary variable would mean that parcels exhibiting that characteristic are 1.5 times as likely to transition to SFR as those that do not. On a continuous variable, an odds ratio of 0.75 would indicate that for each additional unit of the independent variable, the parcel is only 75% as likely to experience a transition. A Chow Test is used to test the hypothesis that a development driver experienced a significant increase or decrease between 2002-2006 and 2006-2012 (Allison 1999).

4.3.2 Data

Data consist principally of Maricopa County assessor records for the City of Phoenix in 2002, 2006, and 2012. While this analysis only investigates housing growth in the region's main municipality, Phoenix includes a broad spectrum of development types including a high proportion of characteristically suburban-style development. Parcels in the final year are matched with their equivalent land area in the base year, relying heavily on ArcGIS software. Many larger agricultural parcels were subdivided in order to build homes, particularly during 2002-2006, making it impossible to simply match the assessor's property number (APN) across years. A spatial matching procedure was developed in ArcGIS to convert the final year parcels into points and identify which base year parcel contained those points. This procedure allows us to match base year characteristics with the parcel's land use type in the final year.

	2002		2006		2012	
Description	Parcels	Sq km	Parcels	Sq km	Parcels	Sq km
Vacant (vac)*	35,486	185.42	39,276	169.08	25,745	160.08
Single family residential (sfr)	288,669	260.94	332,132	288.29	344,620	296.85
Commercial (com)	14,264	56.56	15,867	61.14	15,464	60.81
Industrial (ind)	6,213	57.92	6,847	66.02	7,607	61.68
Agricultural (ag)	3,808	96.32	3,002	52.96	2,327	37.30
Government (gov)	977	24.30	1,323	22.06	1,636	43.14
Other/Unidentified (oth)	690	5.61	917	7.24	1,060	6.33
Education/Medical/Religious (inst)	2,643	33.01	2,667	36.76	3,073	42.90
Multifamily residential (mfr)	49,544	45.53	76,405	50.21	82,235	50.75
Public Parks/Recreation/Reserve (rec1)	1,314	135.47	1,370	135.24	1,290	137.79
Recreation, private (rec2)	4,915	29.95	9,148	47.92	11,781	56.88
TOTAL	408,523	931.00	488,954	936.93	496,838	954.51

Source: Authors' calculations using Maricopa County Assessor's records

**includes parcels coded as surface parking*

Table 4.2: Land use categories and parcel counts, 2002-2012

Assessor's land use codes are aggregated into eleven categories, shown in Table 4.2. In cases where the land use is not available from the assessor, land uses were gathered from the Maricopa Association of Governments, a regional planning body. We were able to successfully identify the land use of approximately 99% of the parcels in

Phoenix. Whether a transitioning parcel is vacant, agricultural, or in an existing, productive land use is included as a driver of development in order to help identify which parcels may be potential sites of greenfield development and which have previously been in some other sort of built up, productive use. A count of the type of parcels that convert to single family housing during each period is shown in Table 4.3. The remaining categories are used to identify the immediate neighbors of each parcel, which again relies on ArcGIS. A 200-meter buffer is drawn around each parcel in order to identify how many parcels of each type are in its vicinity. Figure 4.1 provides an example of the neighbors of a transition-eligible vacant parcel, which includes 80 single family homes, 14 each of vacant and commercial parcels, 2 each of multifamily residential, institutional, and private recreation parcels, one industrial parcel, and no agricultural, government, or public recreation parcels.

	2002-2006		2006-2012	
Prior Use	Count	Percent of total	Count	Percent of total
Vacant (vac)	25,300	58.19%	13,150	87.96%
Agricultural (ag)	15,858	36.48%	796	5.32%
Existing Use (built)	2,317	5.33%	1,004	6.72%
TOTAL	43,475		14,950	

Source: Authors' calculations using Maricopa County Assessor's records

Table 4.3: Parcels transitioning to single family residential use

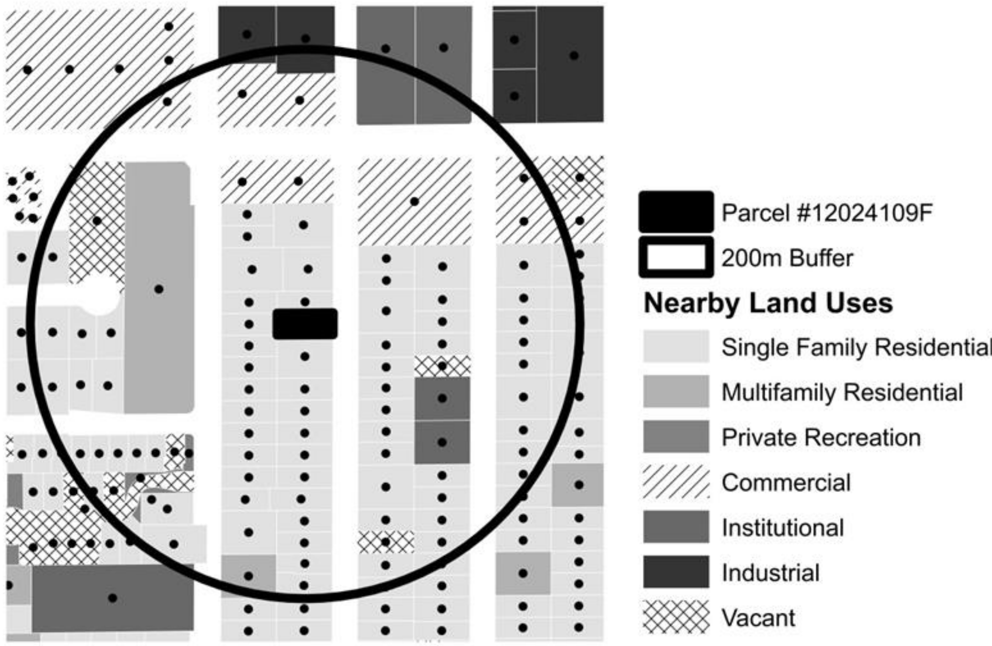

Figure 4.1: The neighbors of vacant parcel 12024109

The Fair Cash Value (FCV) of the land component of a parcel in the base year as determined by the County Assessor is included as an indicator of land cost. Since the data do not indicate whether land was owned by a developer at the time of conversion, we also include the average (per square meter) FCV of parcels within a 200-meter buffer of the target parcel as a broader measure of neighborhood wealth. Zoning data was developed from the city of Phoenix with codes aggregated into six broad categories: commercial, industrial, agricultural, multifamily, low-density single family and high-density single family. Zoning categories were cross-checked against the meeting minutes for city re-zoning hearings from 2000-2012 to ensure accuracy. These categories represent the basic hierarchy of Euclidean zoning and capture parcels likely to experience a transition, while some special-use zoning categories are excluded because they are unlikely to contain any residential property. In order to account for the range in allowable density within single family residential zoning, we split this category at a threshold of ¼-acre per dwelling unit, below which per square foot land values increase substantially.

Other variables were also created using ArcGIS. The population density and percent White, non-Hispanic population are that of the census tract in which the parcel lies, using 2000 U.S. Census figures for the 2002-2006 model and 2005-2009 American Community Survey five-year estimates for the 2006-2012 model. In order to better interpret logistic regression results, population density is treated as a binary variable, taking a value of 1 if the parcel lies in a tract with above average population density and 0 otherwise (1824 people/sq. km in 2000 and 1799 people/sq. km in 2005-2009). Phoenix's light rail line was approved by voters in 2000 and opened in 2008, though special transit-oriented districts were created near station sites as early as 2003 in anticipation of nearby construction (Golub, Guhathakurta and Sollapuram 2012). The transit access variable takes a value of 1 if the parcel is within walking distance (800 meters) of a light rail station and 0 otherwise.

4.4 Descriptive Results

Careful analysis of the conversion data provides numerous insights. Table 4.2 shows the relative hegemony of single family housing in Phoenix, which makes up close to 70% of the parcels and 30% of the city's land area in any given year. Perhaps most striking is the decrease in conversions from 43,475 to 14,950 (Table 4.3), which corroborates the statewide housing starts data presented in Table 4.1. The prior use of transitioning parcels also changes dramatically. During the boom, conversions to single family took place on a blend of agricultural land (36% of parcels), vacant land (58%), and previously built land (5%) while during the recession the percent of conversions taking place on agricultural land dropped precipitously (5%), vacant represented most of the conversions (88%), and built increased slightly (7%). While the drop in agricultural conversions is steep, parcels transitioning from agricultural to SFR often undergo an intermediate vacant classification. During the bust, existing vacant land that had been cleared was far more likely to be utilized for SFR construction versus further attempts to clear agricultural land for development.

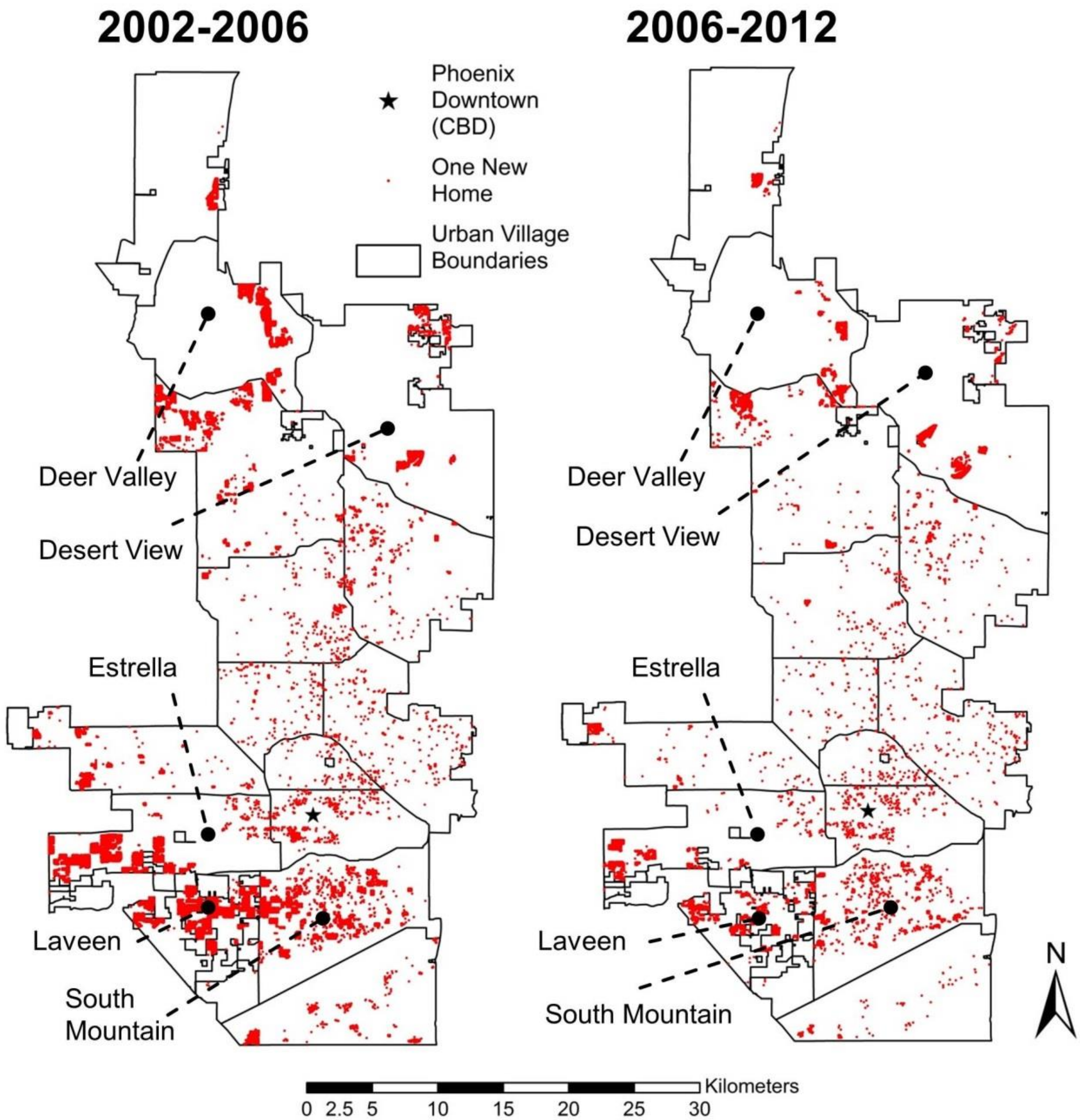

Figure 4.2: Single family residential conversions in Phoenix

An analysis of where single family conversions take place on a map is also considered (Figure 4.2). Atkinson-Palombo (2010) finds that during 2000-2005, three-quarters of single family residential development took place in the Southeast and

Northwest quadrants of the region, though she also notes that the average distance to downtown for a new single family development had decreased compared to previous periods. Table 4.4 indicates that the decrease in single family transitions between our two periods is highest in the urban villages (sub-municipal planning districts) of South Mountain (76.3%), Laveen (70.2%), and Estrella (74.4%). Together, these areas represented 60.3% of Phoenix's new residential development in 2002-2006 and 46.8% in 2006-2012. These are later-developing regions adjacent to a large mountain preserve in the southern portion of Phoenix, which, despite exhibiting many characteristics of fringe development, are much closer to the CBD than other parts of the city, particularly those further north. They are also in the historically Hispanic area known as South Phoenix (Bolin et al. 2005). Two far northern urban villages show an opposite story: the amount of development in Desert View actually increases slightly, pushing its proportion of Phoenix development from 4.2% to 12.4%. While only half as many conversions take place in Deer Valley during the bust, its proportion of Phoenix development increases from 11.6 to 14.9%.

Urban Village	2002-2006 New SFR	2002-2006 Percent of total	2006-2012 New SFR	2006-2012 Percent of total	Percent change
Laveen	9801	22.5%	2922	19.5%	-70.19%
Estrella	9331	21.5%	2390	16.0%	-74.39%
South Mountain	7087	16.3%	1679	11.2%	-76.31%
Deer Valley	5044	11.6%	2223	14.9%	-55.93%
North Gateway	3866	8.9%	1049	7.0%	-72.87%
Maryvale	2067	4.8%	901	6.0%	-56.41%
Desert View	1835	4.2%	1856	12.4%	1.14%
Ahwatukee Foothills	1012	2.3%	203	1.4%	-79.94%
Rio Vista	984	2.3%	360	2.4%	-63.41%
Paradise Valley	862	2.0%	454	3.0%	-47.33%
Central City	488	1.1%	284	1.9%	-41.80%
North Mountain	474	1.1%	253	1.7%	-46.62%
Camelback East	314	0.7%	196	1.3%	-37.58%
Alhambra	209	0.5%	92	0.6%	-55.98%
Encanto	100	0.2%	88	0.6%	-12.00%

[a]Phoenix is divided into fifteen planning regions, known as Urban Villages

Source: Authors' calculations using Maricopa County Assessor's records

Table 4.4: New single family development by Urban Village

Table 4.5 shows descriptive statistics for transition-eligible parcels in 2002 and 2006, i.e. those that are not residential in the base year and thus can be considered as potential sites for new single family housing. The price of available land parcels and nearby land parcels approximately tripled, with 2006 FCV reflecting the peak of the real estate price bubble (Agarwal et al. 2012). The amount of vacant parcels available for development dropped by about 60% from 2002 to 2006 and the number of agricultural parcels dropped over 90%. However, Table 4.2 indicates that the decrease in land area over this period was not nearly as dramatic as the decrease in parcel counts: about 9% for vacant land and 45% for farmland. The neighborhoods of available parcels seem to have changed too – parcels that remain transition-eligible by 2006 tend to be surrounded by more vacant parcels, multifamily residential, and commercial parcels and less likely to be near agriculture. On average, available parcels are slightly closer to the downtown and to subcenters.

Variable Description		2002		2006
Tract population density above the mean for entire city		35%		41%
Tract population: proportion that is White, non-Hispanic		56%		50%
Assessor's land value of parcel in base year (per sqm)	$	49.90	$	154.52
Assessor's land value of the 200m area around a parcel (per sqm)	$	25.45	$	79.83
Distance to the center of downtown (Central & Washington) (km)		14.9390		14.2940
Distance to the nearest subcenter (km)		9.5420		8.4309
Parcels within walking distance (800m) of a light rail station		10,255		10,232
Parcels zoned single family residential, under 4 dwelling units / acre		11,753		7,165
Parcels zoned single family residential, over 4 dwelling units / acre		42,167		24,933
Parcels zoned multi-family residential		67,873		69,772
Parcels zoned industrial		9,749		9,738
Parcels zoned commercial		16,793		18,012
Parcels zoned agricultural		14,419		2,942
Parcels that are vacant in base year		58,170		23,024
Parcels that are agricultural in base year		31,827		2,308
Parcels that are in an existing use (not vacant or agricultural)		104,592		135,630
Avg. num. of nearby[b] vacant (or parking-only) parcels		20.3976		29.9510
Avg. num. of nearby multifamily residential parcels		38.1860		83.1243
Avg. num. of nearby public recreation parcels		0.2264		0.2540
Avg. num. of nearby private recreation parcels		2.0939		2.6310
Avg. num. of nearby single family residential parcels		35.9279		38.6220
Avg. num. of nearby commercial parcels		4.9052		6.1653
Avg. num. of nearby industrial parcels		1.5537		2.0747
Avg. num. of nearby agricultural parcels		3.6640		1.5081
Avg. num. of nearby government parcels		0.3172		0.4314
Avg. num. of nearby institutional parcels		0.7015		0.7162
Total number of parcels		194,589		160,962

[a] *all parcels that are not residential in the base year*

[b] *nearby defined as within a 200-meter buffer*

Table 4.5: Total and mean values for transition-eligible parcels

Talen (2012) alludes to the notion that zoning might not be congruous with actual land use – zoning guides form rather than explicitly creating it. Prior to estimating the empirical models, Pearson's correlation coefficients are calculated between zoning types and select land use categories. Public and institutional land uses are excluded, as are parcels coded as vacant. This is run for 2002 and 2006. Results are shown in Table 4.6 and all are significant at $p < 0.0001$. Single family residential parcels show the highest correlation between assessor's land use category and zoning type, with a 0.54 correlation in 2002 and 0.60 in 2006. Multifamily zoning and the multifamily land use category show a correlation of 0.46 in both years, while commercial zoning and commercial land use are similar: 0.43 in 2002 and 0.46 in 2006. Industrial land uses are correlated with the same zoning type only 30% of the time in either year. Agricultural parcels showed a 0.34 correlation with farm zoning in 2002, but this dropped precipitously to 0.07 in 2006. These statistics confirm that in most cases, the exception to zoning is more likely than the rule. In addition, consistency between zoning and land use is higher for higher-order use types. In order to account for the variation between zoning and actual land use in the model, zoning and land use are considered jointly, e.g. the likelihood of development for an agricultural parcel with a multifamily zoning designation is used as an independent variable. Creating interaction terms between three prior land uses (agricultural, vacant, and existing) with six zoning types yields eighteen such variables.

		2002	2006
Zoning	Land Use	*n = 486,119*	*n = 494,639*
SFR (all densities)	Single Family Residential	0.54215	0.5982
Multifamily	Multifamily Residential	0.46109	0.45621
Commercial	Commercial	0.42908	0.45513
Industrial	Industrial	0.30165	0.30499
Agricultural	Agricultural	0.34068	0.06713

[a]Uses Pearson's correlation coefficients

[b]All results significant at $p < 0.0001$

Source: Authors' calculations using Maricopa County Assessor's records

Table 4.6: Correlation between zoning and land-use

4.5 Residential Conversion Model Results

4.5.1 Goodness-of-fit

Goodness-of-fit measures are found at the bottom of Tables 4.7 and 4.8 and help to analyze the predictive ability of our sets of locational variables over time. The Akaike Information Criterion (AIC) is a commonly used goodness-of-fit measure in non-ordinary least squares regressions – a lower AIC indicates a better overall model fit. We also report the max rescaled R^2 because, although it does not report the percentage of variance explained it is similar to the R^2 found in OLS regressions in that it presents model fit on a scale of [0,1] (Allison 1999).

In 2002-2006, the individual preference model had a max rescaled R^2 of 0.4911, while the developer/supply model had a slightly higher value of 0.5407. A combined model (not shown) including all variables resulted in a value of 0.6007. In 2006-2012, individual/demand variables resulted in a much poorer model fit (0.3980), while the decrease in fit for developer/supply variables was similar, though the value remained higher (0.4635). The predictive power of the combined model was also lower (0.5309).

Overall, the same set of variables do a poorer job explaining the likelihood of parcels developing during the recession, indicating a larger role for external factors not included in the model, such as credit availability which exists at a larger scale than the metropolitan area but may have differentially affected parcels across the study site.

	Boom Years: 2002-2006		Bust Years: 2006-2012		Chow Test[1]
Variable	Coefficient (Std. Error)	Odds Ratio **p*<0.01*	Coefficient (Std. Error)	Odds Ratio **p*<0.01*	Wald χ^2 **p*<0.01*
Above-avg. Pop. Dens.	-0.6216	0.537*	-0.5077	0.602*	2.5271
	(.1732)		(.0354)		
Log Dist. CBD	-0.4030	0.668*	0.5855	1.796*	285.399*
	(.0234)		(.0422)		
Log Dist. Nearest Subctr.	1.0616	2.891*	0.3604	1.434*	361.762*
	(.0251)		(.0331)		
Light Rail Access (1/0)	-0.8784	0.415*	-0.0454	0.956	11.945*
	(.1186)		(.1272)		
Pct. White, non-Hispanic	-1.3700	0.254*	-0.1586	0.205*	7.479*
	(.0448)		(.0619)		
Nearby Pub. Rec. parcel	-0.3135	0.731*	-0.0754	0.927*	585.002*
	(.0177)		(.0098)		
Nearby Priv. Rec. parcel	0.0185	1.019*	0.0059	1.006*	36.922*
	(.0008)		(.0020)		
Nearby Com. parcel	-0.1193	0.888*	-0.0188	0.981*	35.797*
	(.0031)		(.0023)		
Nearby Gov. parcel	-0.0353	0.965*	-0.1845	0.831*	121.296*
	(.0072)		(.0286)		
Nearby Inst. Parcel	-0.0903	0.914*	-0.1625	0.850*	30.562*
	(.0083)		(.0145)		
Nearby SFR parcel	-0.0015	0.999*	-0.0044	0.996*	160.001*
	(.0001)		(.0002)		
Nearby MFR parcel	-0.0196	0.981*	-0.0254	0.975*	133.244*
	(.0003)		(.0005)		
Nearby Industrial parcel	-0.0521	0.949*	-0.3376	0.713*	580.735*
	(.0036)		(.0120)		
Nearby Ag. Parcel	0.0096	1.010*	-0.0011	0.999	388.752*
	(.0003)		(.0005)		
Nearby Vacant parcel	0.0094	1.009*	0.0007	1.001*	2144.542*
	(.0002)		(.0001)		
n | Y (new SFR) = 1	43,475			14,950	
n in model	194,589			160,962	
AIC	131,327			66,916	
max rescaled R-squared	0.4911			0.3980	

[1] Tests the hypothesis that coefficient differs across time periods. A low p-value indicates they differ.

Table 4.7: Individual/demand logistic regression results

4.5.2 Individuals and demand

Results for the individual/demand model are found in Table 4.7. Owing to the large number of observations – nearly half a million parcels in total – almost all estimates are significant at the $p < 0.01$ level. The dependent variable is the log-likelihood of whether or not a parcel experiences a transition to SFR. Odds ratios are a convenient way of analyzing the marginal contribution of a dependent variable, while the Chow Test reveals whether a variable was significantly different between the boom period (2002-2006) and the bust period (2006-2012). We hypothesized, based on theories of "urban inversion," increased commuting costs, and an increased awareness of sustainable development that individuals' preferences for housing during the recession would shift toward areas demonstrating complementary land uses, areas nearer their potential places of recreation, shopping, and work (CBD and subcenters), those with a higher population density, and near the recently completed light rail line.

Being in a census tract with an above-average population density is a negative predictor of development during both the boom (0.537) and the bust (0.602) and change over time is not significant. The variables indicating the distance to downtown and subcenters are interpreted as "the impact of additional distance," so the 0.668 odds ratio in 2002-2006 indicates that being farther from downtown was a negative development predictor. Contrary to the idea of "urban inversion," additional distance from downtown substantially increases the likelihood that a parcel will develop after the bust, so much that this strong negative predictor becomes strongly positive (1.796). The region's subcenters, three of which are located outside Phoenix's city limits, show the opposite effect: being far from a subcenter began as a strong predictor of development (2.891

times as likely to develop for each additional log mile); during the bust its impact is lessened (1.434 times as likely for each additional log mile) and subcenter proximity became less unattractive.

Whether a parcel was within walking distance from a (then-proposed) light rail station was a strong negative predictor of development during the boom years – all other things equal, it was far less likely for a parcel near a train station to become single family housing. This odds ratio climbs to nearly 1 during the bust and although its impact is not clear, it is significantly different from the prior period. Essentially, proximity to the train no longer "repels" single family development. The percent of the population that is White, non-Hispanic is negatively related to development during both periods, and parcels in areas with low minority populations were even less likely to develop during the bust years. It appears that Phoenix may actually be exhibiting "inclusionary" development. Alternatively, this could be an indicator of gentrifying pressures within historically minority areas of the city, perhaps consistent with a "third wave" of gentrification which tends to take place when developers capitalize on cheap property values during a recession in order to turn a neighborhood (Hackworth and Smith 2001).

The remaining variables in the individual/demand model measure the marginal contribution of a single, nearby parcel of a particular type to the likelihood of development. They can represent spatial externalities such as the positive impact of nearby schools, parks, or grocery stores, or the negative externalities associated with nearby industry. Measuring the impact of other parcels under development can indicate the spillover effects of nearby development: during a boom, being near a hot new area might be seen as a positive, but in a recession a nearby foreclosed home or unfinished property could be very undesirable. Some of the categories available in this study do not have the granularity needed to hypothesize whether a nearby parcel would be desired or undesired near a home, specifically for government, commercial, and certain institutional parcels. A neighborhood grocery or coffee shop, an amenity for many individuals, is indistinguishable from a big-box store or a large suburban office park in this data.

Nonetheless, some trends are clear. Nearby public recreation, which consists primarily of city parks and mountain preserves, is a significant negative predictor of development (0.731), but its repellent effect decreases dramatically during the bust (to 0.931) indicating that a nearby park is seen much more favorably as far as residential location is concerned. Nearby private recreation, which consists primarily of golf courses or common spaces in homeowners' associations, is decreasingly valued, though even in the bust its odds ratio is still slightly above one. Nearby commercial parcels show a similar trend, at first exhibiting a significant, negative odds ratio (0.888), but becoming decreasingly repellent during the bust (0.981). To the extent that these represent walkable grocery stores or offices, this would be welcome news to New Urbanists – even a decreasing negative effect for larger commercial establishments like big-box retail would indicate an increased preference for land use heterogeneity. While multifamily developments are often thought to be undesirable attractors of low-income individuals, congestion, and crime (Park, Kwon, & Lee, 2013), results show that proximity to such parcels is only slightly dis-favored, but the repellent effect increases somewhat during the recession. The repellent effect of nearby industry increases dramatically (from 0.949 to 0.713), indicating people may be more willing or able to avoid this negative externality. Finally, the impacts of nearby agricultural or vacant parcels decrease modestly, indicating that parcels near unbuilt or developable land are less likely to convert to housing during the recession than previously.

	Boom Years: 2002-2006		Bust Years: 2006-2012		Chow Test[1]
	Coefficient	Odds Ratio	Coefficient	Odds Ratio	Wald χ^2
Variable	(Std. Error)	**p<0.01*	(Std. Error)	**p<0.01*	**p<0.01*
Log FCV/sq. m - Parcel	-0.1463	0.710*	0.1387	1.149*	1986.113*
	(.0072)		(.0074)		
Log FCV/sq. m - Nearby	-0.1463	0.864*	-0.0950	0.909*	1840.385*
	(.0032)		(.0034)		
Ag - Zoned Low-D SFR	*REFERENCE CATEGORY - NO COEFFICIENTS*				
Ag - Zoned High-D SFR	1.9208	6.826*	2.2625	9.607*	251.398*
	(.0279)		(.0645)		
Ag - Zoned MFR	1.0815	2.949*	2.8493	17.276*	39.959*
	(.0456)		(.0848)		
Ag - Zoned Commercial	-0.7226	0.485*	-0.7081	0.4930	1.202
	(.1261)		0.7112		
Ag - Zoned Industrial	-11.0028	<0.001	-8.5081	<0.001	0.0003
	(57.11)		(62.38)		
Ag - Zoned Farm	0.8115	2.251*	1.6076	4.991*	1.5857
	(.0313)		(.1983)		
Vac - Zoned Low-D SFR	3.4920	32.853*	3.7416	42.164*	50.231*
	(.0332)		(.0454)		
Vac - Zoned High-D SFR	3.1430	23.173*	3.7503	42.533*	10.941*
	(.0236)		(.0368)		
Vac - Zoned MFR	1.7280	5.629*	2.5154	12.372*	6.266
	(.0268)		(.0389)		
Vac - Zoned Commercial	-1.0234	0.359*	0.3585	1.431*	33.981*
	(.1142)		(.0935)		
Vac - Zoned Industrial	-3.4973	0.030*	1.1421	3.133*	67.047*
	(.4482)		(.0924)		
Vac - Zoned Farm	0.7947	2.214*	3.7974	44.583*	1215.904*
	(.0410)		(.0570)		
Existing - Z. Low-D SFR	1.3442	3.835*	0.3450	1.412	42.443*
	(.0855)		(.2245)		
Existing - Z. High-D SFR	0.2611	1.298*	0.5324	1.703*	13.229*
	(.0525)		(.0794)		
Existing - Zoned MFR	-1.2827	0.277*	-1.1512	0.316*	34.448*
	(.0409)		(.0576)		
Existing - Zoned Com.	-2.6862	0.068*	-2.5428	0.079*	1.6690
	(.1731)		(.2158)		
Existing - Zoned Ind.	-4.5783	0.010*	-2.1844	0.113*	9.4837*
	(.5006)		(.2908)		
Existing - Zoned Farm	1.7000	5.474*	-0.2783	0.7570	63.2421*
	(.0945)		(.3215)		
n | Y (new SFR) = 1	43,475		14,950		
n in model	194,589		160,962		
AIC	121,801		60,860		
max rescaled R-squared	0.5407		0.4635		

[1] Tests the hypothesis that coefficient differs across time periods. A low p-value indicates they differ.

Table 4.8: Developer/supply logistic regression results

4.5.3 Developers and supply

The second model is shown in Table 4.8 and analyzes development based on factors pertaining to developer behavior and the supply of housing. Theories about an “oversupply of suburbia” would suggest that greenfield development on inexpensive land that is already zoned for single family homes would be the most likely to develop, particularly during the boom years. Descriptive results, which excluded vacant parcels, showed that zoning is often incongruous with actual land use and that this incongruity became more pronounced during the bust for agricultural land. The average assessor’s fair cash value (FCV) of transition-eligible parcels was much higher in 2006 than in 2002, reflecting the housing bubble.

Development is more likely on cheaper parcels of land during the boom, with an odds ratio of 0.71 on FCV per square meter. A negative, though less extreme effect, is seen for land prices within a 200m buffer of the transitioning parcel (0.864). During the bust, the repellent effect of pricier nearby land is slightly decreased (to 0.909) though a high price of the parcel itself actually becomes a positive predictor of development (1.149). These are the most significant changes of any coefficients. This appears to reflect increased risk-aversion on the part of developers, with a shift away from seeking speculative gains in low-value areas during the boom in favor of development in already desirable neighborhoods.

The jointly-modeled effects of prior use and zoning are more difficult to disentangle than other development drivers, but the predictive ability of these interaction variables is reflected in the model’s relatively high goodness-of-fit. Odds ratios for these variables must be interpreted relative to the reference category, which was chosen as agricultural land zoned for low density, single family residences, i.e. the likelihood of some other use type developing is presented relative to large-lot greenfield development of former farmland. For agricultural land, higher-density zoning is preferred to lower-density zoning and this effect strengthens significantly during the recession (6.826 to 9.607). Agricultural land with a multifamily zoning designation (which does allow for higher-density single family housing in some circumstances) was very unlikely to develop during the boom years, but the odds ratio increases dramatically thereafter (0.485 to 17.276). We hypothesize that commercial or industrial zoned parcels, regardless of use type, only convert to single family homes in somewhat unusual cases, such as the "rescuing" of a previous, failed development or an one-time (but major) change in local land use plans. We do not believe that this model, which only considers mean effects, reflects any particularly strong trends in such idiosyncratic cases. Farmland that retains agricultural zoning is more likely to develop than low-density single family zoned agricultural land, but less likely than most other categories. This does not change significantly during the recession, leading to the belief that an agricultural zoning designation slows some farmland conversion in comparison to farmland zoned for other uses, though not all.

Parcels designated as vacant are more likely to develop than agricultural land in most cases – a distinction that increases substantially in the bust, during which vacant land dramatically overshadowed agricultural land as the use type most likely to develop. During the boom, low-density zoned vacant parcels are more likely to develop than their higher-density zoned counterparts (32.853 vs. 23.173), though in the recession the difference between the two becomes negligible (42.164 vs. 42.533). The shift away from development on lower-density zoned land is true for existing parcels as well. As was true for farmland, development is also increasingly likely on multifamily zoned vacant land (5.629 to 12.372). We can only speculate that the high odds ratio on already built, farm-zoned land during the boom is reflective of a handful of peculiar cases; it decreases and becomes insignificant during the bust.

4.6 Discussion

This study analyzes how drivers of single family residential development changed during the recession. The analysis was structured around a distinction between drivers of housing supply (developer behavior and the constraint presented by zoning) and housing demand (individuals and their preference for place) whilst seeking to gain an empirical understanding of the contention that the recession may be fundamentally changing urban development patterns.

Considering Phoenix's historical development trajectory, the drivers of new housing from 2002-2006 are not unexpected: lower-cost, lower-density areas on converted farmland in the interstices between the region's subcenters are likely to develop. However, the seemingly inverted results for distance to downtown (positive predictor) and distance to subcenters (negative predictor) need to be interpreted with caution due to the city's layout. The urban villages of South Mountain, Laveen, and Estrella have already been identified as representing a sizeable component of boom-era greenfield development (Table 4.4). These areas have smaller parcel sizes compared to those at the urban periphery as well as historic minority and low-income populations, making them less attractive to large developers until the early 2000s when they first were seen as viable alternatives to fringe development in northern Phoenix. Because of the particular history of South Phoenix, developers during the boom converted a large number of agricultural and vacant parcels that were quite close to downtown. Many of these parcels were less expensive, inhabited by racial minorities who secured subprime mortgages, and were more likely to suffer foreclosure (Agarwal et al. 2012). These results support the critical narratives of Crump et al. (2013) and Schafran (2013) and show a reciprocal effect of the global recession on local development – which appears to have ground to a halt in these areas. They also support the findings of Immergluck (2010): not only are foreclosure rates higher, but future development is disproportionately stalled in newer communities financed during the boom years.

Some evidence is found to support the theory of a recession-induced "urban inversion" as envisioned by Leinberger (2008), despite the obscured results for distance to downtown and subcenters. The light rail is one of the few examples of compact growth that was actively promoted by local authorities and it shows a much-decreased repellent effect. While we can only speculate that this coefficient would increase further if multifamily development were included in our model, Golub et al. (2012) demonstrated that proximity to the Phoenix light rail increased the value of single family, multifamily, commercial, and vacant properties even before it opened. The substantial increase in the odds ratios for commercial and public recreation parcels is also encouraging for compact growth advocates as it suggests an increased value of complementary land uses near single family homes. While Immergluck (2010) did not find evidence that foreclosures were more prevalent in fringe areas, we do find evidence that these areas became less attractive for subsequent development: agricultural conversion grinds to a halt, representing a dramatic shift away from a development pattern which had been extremely important throughout the city's history (York et al. 2011a, Luckingham 1989). Cost variables also indicate that developers are more willing to develop more expensive land parcels with more expensive neighbors – in neighborhoods that are already established and less speculative in nature.

The low correlation between zoning and land use (which excluded vacant parcels) originally seemed to indicate that zoning does not represent a substantive constraint on development. With the exception of agriculture, these correlations stayed the same or increased between 2002 and 2006, suggesting that any changes in zoning policy, if anything, had the effect of increased consistency especially as it relates to single family development. We can only speculate as to the cause of the decreased consistency relating to agricultural zoning; it is most likely related to the property tax exemptions given to agriculturally zoned land.

Despite these consistency issues, the goodness-of-fit scores indicate that zoning and land use considered jointly (along with cost) are more able to predict new development than all of the variables used to model individual demand. Once the actual land use of a parcel is taken into account, zoning does appear to be a strong determinant of which parcels will develop: vacant or agricultural parcels with a less restrictive single family designation are overwhelmingly likely to convert. An interesting shift is the relative decline in preference for low-density SFR zoning. During the boom years, built and vacant parcels showed a far higher likelihood of converting if they carried a low-density zoning designation, while afterward the odds ratio of higher-density zoned parcels (SFR or MFR) increased. On the one hand, this could represent a decreased preference for the large lots that typify fringe development, while developers may see low-density zoning as a constraint on their ability to build more homes on the same amount of land. While agricultural zoning might have a slight effect in "saving" farmland from development, it is not substantial and again we speculate that developers may be attempting to maintain an agricultural designation for as long as possible in order to secure a tax exemption.

Other anomalies which arise from the analysis might indicate certain idiosyncratic cases. The 17.276 odds ratio on multifamily-zoned farmland during 2006-2012 can be traced to three large developments in South Mountain and Laveen which contain nearly all of Phoenix's multifamily-zoned agricultural land. In 2006, these properties had been subdivided and zoned for multifamily use (which under certain circumstances can accommodate higher-density detached homes), though they remained classified as agricultural land. By 2012, all three developments were in various stages of completion: one was nearly complete, another about 2/3 built, and the third containing only 37 built homes out of over 200 planned. These three instances of so-called "arrested development" show how zoning can easily reflect the expectation of development – many projects change the landscape yet remain unbuilt. Considering how infrequently zoning reflects the actual land use of a parcel, it is surprisingly resilient as a predictor of which parcels are likely to develop, even during the recession. Thus, findings demonstrate that the municipality has at least some agency in development, in contrast to the perspectives that the "Growth Machine" has come crashing down along with home prices. These results are also reassuring, indicating that properly constructed municipal land use institutions might be an effective mechanism for more equitable land use even in changing economic conditions.

However, it is also important to keep in mind the increased effect of unmodeled factors during the recession: on the whole, the set of place- and parcel-specific drivers of development we include explains significantly less of the variation in development than during the boom. We take this to mean that external factors and risk played greater roles for both individuals and developers. Decreases in individuals' home equity impacted their mobility and ability to express preferences, while developers were no longer willing or able to finance speculative homebuilding. Whether a project was completed, cut short, or abandoned may depend on the developer's finances or simply the timing of its construction, factors which have little to do with the specifics of the location itself.

4.7 Conclusion

The global recession which followed the housing collapse had a significant "human toll," evidence of which can even be found in our results related to South Phoenix. Many have already explored the factors by which a local crisis escalated into a global one; less clear is the lasting impact of the global recession on urban form and development decisions. For some, the Phoenix case is a particularly extreme example: not only is sprawling suburbia financially unsustainable, the environmental impacts in the fragile desert ecosystem (not to mention global climate change) are environmentally perilous: the recession *must* force change (e.g., Ross 2011). Furthermore, Bruegmann (2005) emphasizes that "urban form is both an effect and a cause of economic conditions."

Though zoning appears to remain an important constraint on development despite its low correlation with actual land use, some of its specific impacts, such as the ability of an agricultural zoning designation to "stave off" development pressure merit further study. Explicitly linking policy changes to different zoning decisions and development patterns is a logical next step, while a full panel of assessor data would enable more accurate tracking of development timing.

The sheer magnitude of the recession's impact on new housing is reflected in the finding that only 1/3 the amount of new, single family homes were built during 2006-2012 compared with the prior period. More nuanced results are also found: a precipitous drop in agricultural conversion, decreased likelihood of speculative development, and more new homes closer to complementary uses – all of which are encouraging trends for those emphasizing compact cities. Changes in multifamily housing remain unexplored but likely corroborate these findings. It is clear that developers must respond to individuals' demands for particular types of housing in order to convert their resources and effort into a marketable product, and in some ways our results suggest that developers are providing new homes that are near other uses and are less speculative in nature. In other words, housing supply may now be more responsive to locational preference.

While our empirical analysis considers only Phoenix, we find evidence of a shift in development decision-making in a city whose main industry is said to be "growth itself" and whose mythical name reflects its penchant for boosterism and obsession with newness (Gober 2006). If homeowners and developers in one of the most extreme examples of sprawled suburbia appear to be evolving, the lasting impact of the recession on urban form will be substantial – and perhaps not exclusively detrimental.

CHAPTER 5

A SURVIVAL ANALYSIS OF LAND-USE CHANGE

5.1 Introduction

Urbanization, suburbanization, and land fragmentation have critical impacts on environmental and social systems in cities. Changes in the spatial structure of cities affect ecological functions such as hydrology and biogeochemistry (Grimm et al. 2008) as well as the social environment, built environment, and even global financial markets (Aalbers 2009). However, decisions of whether to convert urban land take place at a spatially disaggregated scale with individual landowners deciding to convert parcels of land from one use to another (Irwin 2010). Designing effective policies to address environmental and social concerns over urban land-use change requires an understanding of the economic, institutional, and spatial drivers undergirding these decisions.

Greenfield development, which often refers to the conversion of agricultural land to urban uses (principally residential uses) has long been a rallying cry for environmentalists. Farmland preservationists, conservationists, and proponents of food security have considered the loss of agricultural land – and in particular agricultural land near urban areas – to be a major concern (Benfield, Raimi and Chen 2001, Godfray et al. 2010). Specific policies aimed at preserving farmland have been proposed and implemented by government entities (Liu and Lynch 2011), while zoning, a more general tool, has been used toward this and other goals but is often seen as ineffective or ambiguous in terms of net effect (Butsic, Lewis and Ludwig 2011, Talen 2012, York and Munroe 2010). In addition to land preservation, "excessive" development, particularly on the urban fringe, has been implicated in a host of ills including environmental degradation (Benfield et al. 2001), redundant spending on municipal services (Green 1998), and decreased social interaction (Putnam 2000). Large-lot zoning at the urban fringe in addition to fragmented municipal boundaries have been identified as causes of excessive conversion of land and in turn an expanded urban footprint (Carruthers 2003). Meanwhile greenfield development is generally considered to be less expensive, more desirable, and easier to finance by developers than infill or brownfield development (Peiser 2001, Leinberger and Alfonzo 2012).

Spatially-explicit modeling has uncovered a wealth of potential drivers of land-use change (Irwin and Bockstael 2002, Seto and Fragkias 2005, Newburn and Berck 2006). A spatially disaggregated approach can link the observed land use outcome (namely, development) to the regulations, locational attributes, or externalities that led to the change. Not only is this approach useful for explicitly analyzing alternative policy options (Wrenn and Irwin 2012), but it can also be used to analyze the social equity implications of land ownership change (Pfeiffer and Molina 2013) or evolving preferences for neighboring land uses (Kane et al. 2014c). Economic performance, particularly in the United States, is fundamentally tied to the housing market and in turn to the unique geographies of where housing is built (Martin 2010). Foreclosures and changing development patterns during the recent global financial crisis have highlighted the sensitivity of urban spatial pattern to booms, busts, and economic shocks (Kane et al. 2014c, Crump et al. 2013, Immergluck 2010). More generally, the timing of urban development has a lasting impact on the form and character of cities as well as future prospects for urban sustainability (Boone et al. 2012). Lot sizes, building durability, landscaping, and transportation infrastructure are largely a product of the historical period during which development in an area first took place (Kane, Connors and Galletti 2014a, Adams 1970).

Modeling of urban land-use change is complicated by appropriately treating both spatial and temporal resolution (An and Brown 2008). On the one hand, identifying behavioral drivers requires the scale of the analysis to match the boundaries at which land is discretized: individual land parcels (Irwin 2010). Large cities have hundreds of thousands of parcels whose boundaries change frequently. Survival analysis, also referred to as hazard analysis or event history modeling, is a parsimonious means of capturing the time-varying aspects of development trajectories to understand longer-term trends in land change (An and Brown 2008, Wrenn and Irwin 2012). Given the boom-and-bust nature of many housing markets and that the greatest changes in urban land use occur during building booms, spatially-explicit, long-term survival analysis is well-suited for understanding behavioral drivers behind the conversion of agricultural land.

This paper uses survival analysis to investigate the spatial, institutional, and economic drivers of agricultural conversion in the Phoenix, Arizona metropolitan area. Using remotely-sensed imagery to identify agricultural land, a Cox proportional hazards model identifies if and when a unit of agricultural land experienced a conversion to residential use at any time between 1992 and 2013. Since land ownership boundaries do not remain consistent over this period, agricultural land is identified using satellite imagery and a lattice is used to create cells of agricultural land at three scales: 60x60m, 90x90m, and 360x360m. Residential certificates of occupancy acquired at the municipal level provide geocoded point data for each new home constructed during the study period. The Phoenix metropolitan area is known for its fast growth, real estate booms and busts, and heavy reliance on the home construction industry for its economic base (VanderMeer 2002, Gammage 1999, Gober 2006). Its history is dominated by the widespread conversion of both agricultural and open desert land into affordable housing, though the trend of greenfield development has slowed dramatically since 2006 (Kane et al. 2014c). Additionally, the environmental sensitivity of the region's desert ecosystem – particularly in terms of water use and the urban heat island effect – puts a premium on understanding drivers of land conversions there (Connors et al. 2012, Myint et al. 2013).

5.2 Land Conversion Model

The conversion of agricultural land is a complex process involving numerous actors, institutions, and decisions, even in a fast-growing region like Phoenix. Most simply, a developer offers to purchase a farmer's land if he determines that his expected future returns from constructing housing are greater than the cost of acquisition. A farmer sells his land to a developer if the price offered is greater than his expectation of future agricultural rents. The land would be subdivided with homes built and sold in relatively short order. During the housing construction boom of the late 1990s and early 2000s in Phoenix, this process could be described as a "well-oiled machine" with title transfers, zoning changes, platting, and construction taking place quickly and efficiently – and motivated by high returns. Even still, both market and institutional factors impact the speed and complexity of the process. For example, in Maricopa County as in much of the United States, land that is in qualified agricultural production is appraised based on agricultural rents resulting in a very low tax burden for the owner. In contrast, vacant land that is not in production is appraised based on its potential for income-producing urbanized uses such as housing, resulting in a tax burden several times higher (2012). In

Maricopa County – and particularly during the recent global financial crisis – it was common practice for developers or investment groups to purchase property and lease it back to a farmer in order to maintain tax benefits, but with the flexibility to convert to housing should market conditions improve. In this region, agricultural zoning is not used to slow development pressure and is easy to change. Farmers make land sale decisions based on expected return rather than any land conservation or historic preservation policy, which are common elsewhere (Bausch et al. 2015).

While market conditions, zoning, and tax liabilities complicate the understanding of land ownership, the purpose of this study is to observe land-use outcomes and the resulting urban morphology. As such, we abstract the transaction between farmer and developer and model only one actor: a landowner who can choose to convert a unit of farmland into housing. The landowner's profit maximizing decision, adapted from Wrenn and Irwin (2012), involves choosing the optimal time t^* for development of land unit i in order to maximize future rents:

$$(1) \qquad \max \pi_{it} = \int_0^t A(x_{it}, t^*) e^{-rt} + \big(H(x_{it}, t^*) - C(x_{it}, t^*)\big) e^{-rt}$$

where r is the discount rate, A is the discounted value of agricultural rents, H is the present discounted rent that can be expected from housing, and C is the present discounted cost to convert the parcel. Each of A, H, and C depend on both the spatially-explicit characteristics of land unit i and also t^* which represents the local housing market, the agricultural commodities market, and other market conditions affecting the profitability of land conversion. These can operate anywhere from a metropolitan to a global scale. $H(x_{it})$ includes factors specific to land unit i such as intraurban location, proximity to transportation networks, and inclusion within the boundaries of a municipality. $A(x_{it})$ consists of the soil quality and the cost of water for irrigation. The latter is omitted due to data availability constraints, though water costs in the area are closely tied to energy costs as energy is used for pumping groundwater and moving surface water through irrigation systems (Scott et al. 2011). $C(x_{it})$ is left unexplored in this paper but would include any other variation in the cost to convert farmland into housing. It could vary if certain parts of towns charged developer impact fees, required the construction of infrastructure, or land slope increased the cost of per-unit home construction.

While a landowner's decision to convert farmland into housing operates continuously, the empirical specification is complicated because thousands or millions of units of agricultural land are continuously at risk of conversion. The reality in land change science is that continuous information is unlikely to be available or manageable for every parcel of land for a long-term study period. Following An and Brown (2008), a discrete-time model can be used to approximate a continuous-time process even when the temporal resolution is fairly coarse. While a logit or complementary log-log specification models discrete time explicitly, these discrete models converge to the (continuous) Cox proportional hazards model as the time interval decreases (Thompson 1977). The temporal resolution in this study is one year; i.e., a record is created for each land unit for each year in which it "survives," or until the end of the study period if it does not convert at all. This paper's 90m resolution model, for example, studies 44,539 transitions on 266,132 transition-eligible land units resulting in 5,581,796 regression observations. This feature allows for the consideration of time-varying covariates which do not remain consistent over the study period. For example, as new highways are built, each land unit's proximity to the transportation network changes.

This study uses a continuous, semi-parametric Cox proportional hazards model with time-varying covariates. An event is defined as a residential completion on a unit of land that was in agricultural use at the beginning of the study period. The probability of land surviving in agricultural use beyond time *t* is given as the survival function, *S(t)*:

$$(2)\ S(t) = \Pr(T > t) = exp\left\{-\int_0^t h(x)dx\right\}$$

The hazard function $h_i(t)$ models the failure rate of each individual *i* and can be considered conditionally upon a set of covariates. The Cox model considers the logarithm of the hazards against a linear combination of *k* covariates:

$$(3)\ Log\ h_i(t) = \alpha(t) + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik}$$

Results reflect the cumulative impact of each covariate on the landowner's decision-making processes over the entire study period or until conversion. Using discrete measurements of time in a continuous model requires an approximation procedure to distinguish between transitions that occur during the same year – the EFRON procedure has been shown to be effective and computationally efficient (Allison 2010). Finally, the Cox model estimates coefficients by comparing the hazards of any two parcels, meaning that $h_i(t)$ is not directly observed. Rather than assuming a parametric baseline hazard function $\alpha(t)$ such as a Weibull or exponential distribution or relying on binary time steps in a discrete-time model, we allow metropolitan-area wide indices of housing price and agricultural commodity prices to characterize the hazard that each unit of land will observe. As a test of the robustness of our methodology, two discrete-time specifications are also estimated: a logit and complementary log-log model.

5.3 Study Area and Data

The study area is Maricopa County, Arizona (Figure 5.1). The county contains nearly all of the population and developed land in the Phoenix metropolitan area – only a small portion lies in neighboring Pinal County. Despite its desert environment, Phoenix was originally established as an agricultural settlement in the late 1860s, utilizing an abandoned canal system built by the ancient Hohokam people several hundred years prior (Luckingham 1989). By 1934, the County's urbanized area totaled 8,557 acres and by 2010 had swelled to nearly 400,000 acres (CAP-LTER 2012). The city's booster mentality which saw growth itself as the main industry contributed to rapid conversion of both open desert land and farms. As a result, Phoenix has been particularly susceptible to economic booms and busts. The global financial crisis of the late 2000s dramatically impacted the conversion of single-family housing, the region's dominant construction type (Kane et al. 2014c) suggesting that market conditions are likely to have a lasting impact on urban morphology. In fact, land cover patterns in Phoenix are found to have significantly varying levels of fragmentation and shape based on when areas were built, reflecting the heavily path-dependent nature of present-day land use pattern (Kane et al. 2014a).

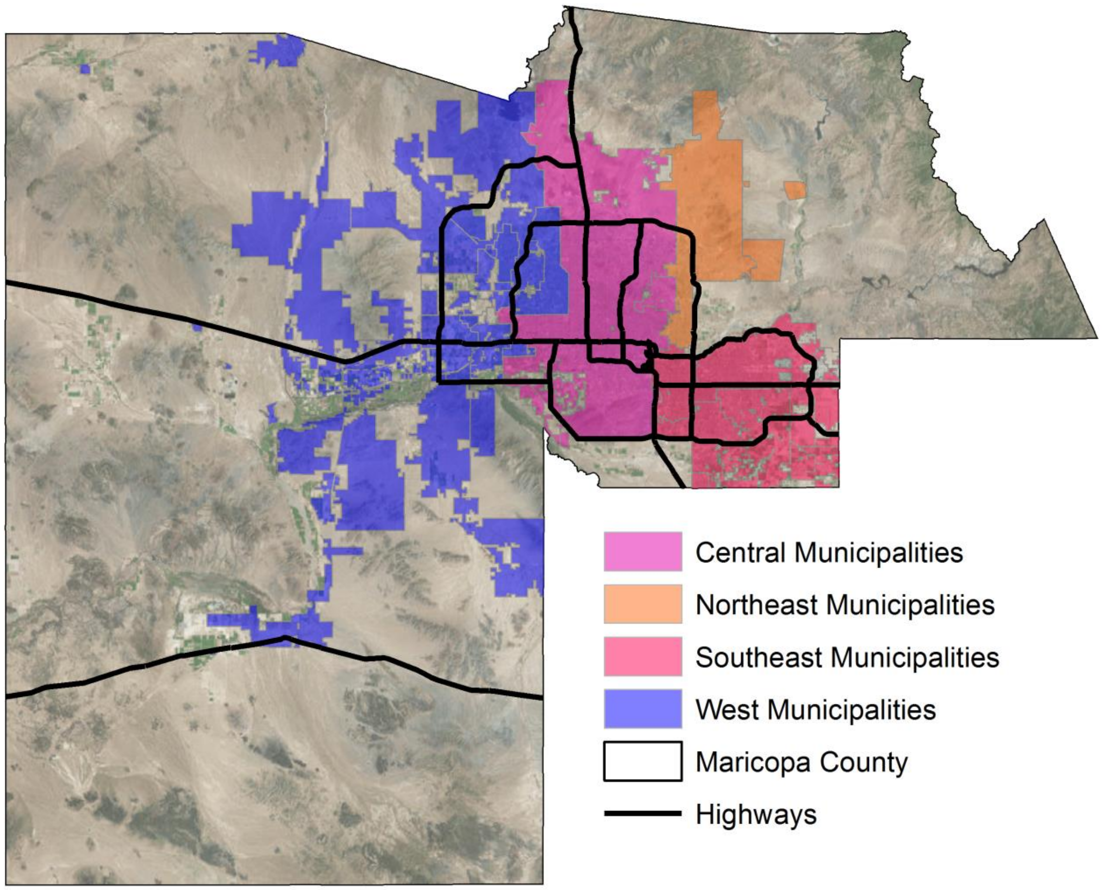

Figure 5.1: Maricopa County, Arizona

5.3.1 Satellite Imagery and Agricultural Land

The U.S. Geological Survey provides a series of freely-available, satellite imagery of the entire country beginning in 1992 called the National Land Cover Database or NLCD (Vogelmann et al. 2001). These raster images classify 30 meter square pixels of land into 21 discrete land cover categories including agricultural, barren, forest, wetland, and a variety of urbanized uses (Table 5.1). While the use of NLCD imagery has been critiqued for its accuracy in humid regions with high levels of tree cover (Irwin and

Bockstael 2007, Stehman et al. 2003), desert regions like Arizona do not suffer from these problems (Shrestha et al. 2012). This study considers four categories as farmland: pasture/hay, row crops, small grains, and fallow land. Further criticism that the NLCD resolution of 30m is too coarse to identify residential patterns is avoided since its only purpose in this study is to identify agricultural land. Using ArcGIS software three lattices, or grids, of 60x60m, 90x90m, and 360x360m are constructed on top of the entire raster imagery and whether or not each grid cell contained agricultural land was identified. Cells were categorized as either agricultural land or not; the latter are discarded from the analysis (see Figure 5.2).

Category	Description	Quantity in study area - km2
Water	Open Water	75.38
	Perennial Ice/Snow	-
Developed	Low Intensity Residential	760.08
	High Intensity Residential	14.96
	Commercial/Industrial/Transportation	462.29
Barren	Bare Rock/Sand/Clay	764.53
	Quarries/Strip Mines/Gravel Pits	9.01
	Transitional	19.09
Forest	Deciduous Forest	9.09
	Evergreen Forest	315.75
	Mixed Forest	3.15
Shrubland	Shrubland	18,293.27
Non-natural woody	Orchards/Vineyards/Other	49.50
Herbaceous Upland	Grasslands/Herbaceous	1,004.60
Planted/Cultivated	Pasture/Hay**	216.84
	Row Crops**	1,211.18
	Small Grains**	471.37
	Fallow**	-
	Urban/Recreational Grasses	147.19
Wetlands	Woody Wetlands	45.01
	Emergent Herbaceous Wetlands	12.51
**adapted from Vogelmann et al., 2001*		23,884.79

***Included as agricultural land in this study*

Table 5.1: NLCD land cover categories

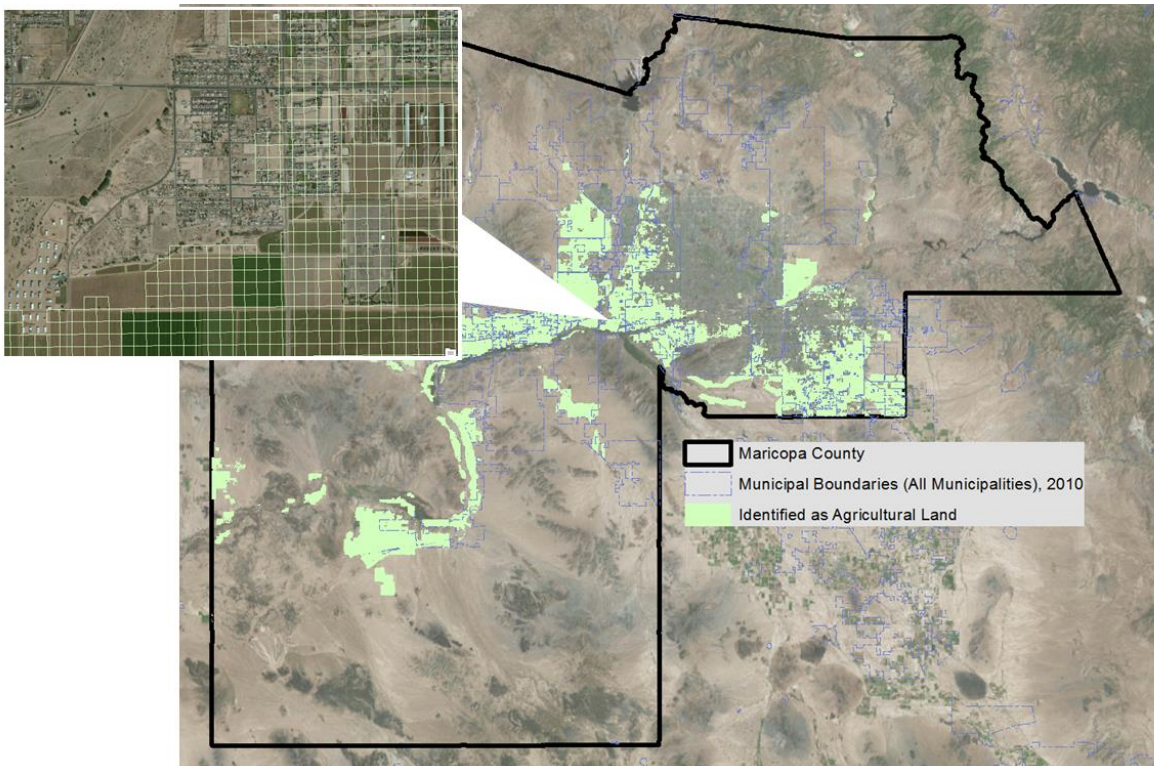

Figure 5.2: Agricultural land identified by NLCD (90m)

5.3.2 New Residential Construction

The Maricopa Association of Governments (MAG), the Phoenix area's regional planning authority, has maintained a database of county-wide residential completions since 1992. When a certificate of occupancy on a new dwelling is issued by any municipality in the County, it is forwarded to MAG for inclusion in the database. 585,018 residential completions were recorded between January 1, 1992 and December 31, 2013.

5.3.3 Spatial Scale

Results of any land conversion analysis can be highly sensitive to the resolution of the observations chosen. Studies often use individual land parcels as a unit of observation in order to preserve the connection between parcel characteristics and the decision to develop (see, e.g., Kane et al. 2014b, Irwin 2010). Modeling agricultural conversions over a long time period becomes complicated since parcel boundaries change frequently, especially when land is broken up for development. While creating grid cells is a means to standardize land boundaries over time, varying the size of the cell changes what an observation represents. Since agricultural grid cells are identified as land having *any* agricultural land, larger cells are likely to capture more of the adjacent area including roads, existing buildings, and so forth. As such they cover more of the city and include a higher number of the total new residences built. Furthermore, cells are identified as "converting" if and when *any* new residence is built thus as the cell size increases more residential completions appear to have taken place on former agricultural land (Table 5.2).

Resolution	Number of ag cells, 1992	Number of ag cells that convert to residential, 1992-2013 total	Area per cell (acres)	Number of average-sized homes per cell*	Average number of actual new homes on converting cells	Residential completions on former ag land
360m	20,434	6,362	32.0	112	46.26	294,312
90m	266,132	44,539	2.0	7	5.89	261,109
60m	573,474	80,689	0.9	3	3.15	254,861

**based on approximate average residential density of 3.5 units per acre*

Table 5.2: Agricultural cell conversion at multiple resolutions

This is a version of the well-known modifiable areal unit problem (MAUP) (Openshaw and Taylor 1981) and has no particular solution since the size of both farms and residences varies. Some guidance can be sought by considering their sizes in general terms, while conducting analysis at multiple resolutions provides a test of robustness. Low-density residential development is typically considered to be approximately 4 units per acre, or 10,890 ft^2 (Steiner and Butler 2012), while an analysis of residential lot sizes in Maricopa County conducted in 2000 found an average size of about 7,200 ft^2 for new homes region-wide (Rex 2000). A Phoenix-area developer's handbook which suggests a region-wide average of 3.5 dwelling units per acre (12,446 ft^2) may be a more accurate assessment of residential lot size since it includes streets, sidewalks, and other rights of way which would need to accompany farmland conversion (Bronska 2011). Figure 5.3 shows a neighborhood in Avondale, Arizona complete with residential conversions and the agricultural land lattice at all three resolutions. The 360m grid cells clearly identify a higher proportion of agricultural land as having converted to housing. Based on average lot sizes, one 360m cell could accommodate 112 houses, but in the data they contain an average of 46 homes (Table 5.2). The number of actual residential completions on 60m and 90m resolutions is much closer to the number that could be accommodated based on average lot sizes, indicating that these scales better reflect the residential conversion process. While theoretically the scale could be further reduced to 30m, this runs the risk of zonation effects and invites geocoding accuracy issues.

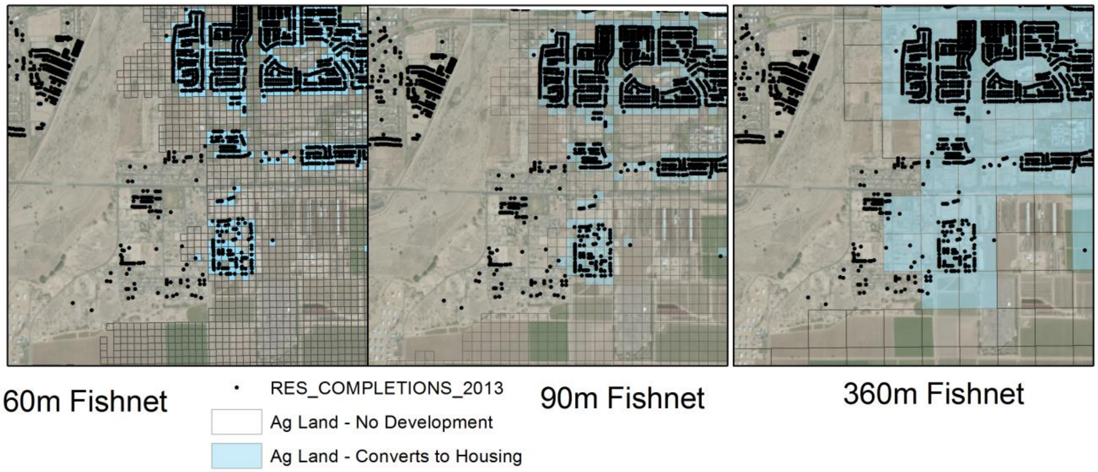

Figure 5.3: Land conversion at multiple resolutions (Avondale, AZ)

5.3.4 Spatial Covariates

Urban economic theory posits a tradeoff between access and space in the determination of where people choose to live (Anas et al. 1998, Phe and Wakely 2000). This is often manifested in the aphorism that homebuyers should "drive until they qualify" (for a home mortgage loan) and is a reflection of decreasing land rents farther from the city center. While the urban density gradient has been bent by polycentricity – particularly in Phoenix (Leslie and Ó hUallacháin 2006) – the Euclidean distance to downtown is still a useful means of gauging, in general, whether a new residence is close to the urban core, on the urban fringe, or in-between. Using the logarithm of a new home's distance to downtown plausibly assumes a nonlinear decay function, and conformance to a monocentric city assumption would yield a negative sign. The Phoenix metropolitan region is typically broken up by local developers and residents as consisting of the west, southeast, and central sub-regions, the latter of which consists mainly of the city of Phoenix. A smaller northeast sub-region does not fit the typical descriptions and mostly consists of the city of Scottsdale. Southeast, central, and northeast dummy variables are considered relative to the reference category, west (see Figure 5.1).

Both agricultural rent and development costs are impacted by the soil quality. Better soils require less maintenance and irrigation, lowering the cost per unit of farm output. A contention of conservationists is often that prime agricultural lands are at the highest risk of development, in particular since cities were originally formed in fertile areas (Benfield et al. 2001). However this is largely an issue of perception since the price of expensive farmland near urban areas is largely due to its exchange value, not necessarily its agricultural productivity (Hart 2001). Since soil quality is a fairly static characteristic of the land, this study relies on the U.S. Department of Agriculture's most recent soil survey as a covariate. Soil samples are digitized and were based on field surveys conducted between 2010 and 2013 (NRCS, 2014b). The suitability of land for agriculture is divided into four categories from best to worst: farmland of unique importance, prime farmland if irrigated, prime farmland if irrigated and either protected from flooding or not frequently flooded during the growing season, and not prime farmland. A small area of Maricopa County is located in the Tonto National Forest for which soil survey data is not available, though this land is left in the model for completeness.

5.3.5 Institutional Covariates

During the study period highway construction was rapid: in 1992, Maricopa County had 265 miles of limited-access freeways; a combination of interstate highways, federal, and state roads. By 2013, this had increased to 461 miles (author's calculation). Freeway access is considered extremely important to real estate development generally, and in Phoenix in particular (Tian and Wu 2015). Induced development has always been a concern with respect to freeways, as plans for freeways lead to more building that is increasingly dependent on freeway access (Kamel 2014). In order to account for the changing freeway map over our study-period, a time-varying covariate *Hwymiles* is added and is the Euclidean distance from the cell to the nearest highway that had been built by that year. The anticipated negative coefficient would indicate that proximity to a freeway increases the likelihood of development.

While zoning designation is typically considered in models of urban land-use change, the ease of changing agricultural zoning to some other category in Maricopa County means that its impact on housing construction is lessened (personal communication with a former Phoenix city planner, October 2014). Kane et al. (2014c) find mixed results regarding zoning before and during the recent recession, though the relationship between land use and zoning became noticeably less concordant following 2006. Most municipalities in the region pursued an aggressive growth strategy that involved annexing adjacent unincorporated lands, often sparring with one another in an attempt to avoid being hemmed in and excluded from future growth opportunities (Heim 2012). This study considers both whether a grid cell was incorporated at the time of its conversion, and if so, how long since it had become part of a municipality. Whether or not land is incorporated is a rough indicator for the existence of city services and other factors that could increase the likelihood or speed with which agricultural land is converted to housing. However, it is likely that land annexation and development operate hand-in-hand: the plans for a new residential development are likely to involve discussions and action regarding its potential inclusion in a municipality. Since this may result in an endogenous regressor, we also include the length of time between annexation and land conversion as a covariate, i.e. are more recently annexed areas more likely to convert? A negative coefficient would provide some evidence for endogeneity. It is also possible to test the contention that construction on recently annexed land is more prevalent during booms using an interaction term. In other words, is there a joint positive effect of the recentness of annexation and high home prices?

5.3.6 Housing Market

An advantage of survival analysis in land-use change modeling is that spatially and temporally-varying covariates can be compared. As shown in equation (1), a landowner's decision to convert land is a maximization of the present value of profit from housing versus farming. This study uses the All-Transactions House Price Index for the Phoenix-Mesa-Glendale, Arizona metropolitan statistical area (MSA) provided by the Federal Reserve Bank of St. Louis to measure the variation in housing market conditions over the study period (FRED 2014). While the potential profit from land conversion necessarily involves myriad other factors that vary at a finer spatial scale, the land's location, accessibility, and municipal inclusion are already included separate which helps to avoid endogeneity between these covariates and individual land prices. A positive sign is expected, i.e. a higher housing price index will increase the hazard of land conversion. A possible complication is that housing construction is not instantaneous: the decision to develop is a reaction to current market conditions, while these data record land change once homes are fully built. To account for the difference in time between the decision to develop and the point in time at which land conversion is complete, we compare the marginal effect of same-year price indices with prior-year indices and values for two years prior. All price indices used in this study were inflation-adjusted using the producer price index (PPI).

5.3.7 Agricultural Commodities Market and Oil Prices

Commodity crops have been a part of the Phoenix area's economy since it was first settled in the 1860s. Two of the most prevalent in the arid desert region are cotton and alfalfa hay. In order to characterize the value of surviving (i.e. remaining as farmland), this study considers the variation of the price index of these two crops over the study period. The global index of cotton price is provided by the National Cotton Council (2014a) and provides a measure of Phoenix-area crop in a global market. Arizona alfalfa hay prices are acquired from the U.S. Department of Agriculture and reflect a regional market feed crop (USDA 2014). Real crude oil prices are often used as an indicator of the input price to farm production, as they are a component of both fuel for machinery and a component of fertilizers. However, oil prices have a more complex relationship with other economic measures. While low oil prices are often a bellwether for economic conditions and are associated with higher U.S. stock market prices, oil prices are endogenous to many components of the economy and the response of stock, capital, or housing markets may depend on what caused the change in oil price (Kilian and Park 2009). A negative coefficient would suggest they are more important for homebuyers than for farmers, i.e. higher oil prices decrease consumers' ability to purchase new homes and therefore decrease the hazard of land conversion.

An additional hypothesis using an interaction term can investigate to what extent oil prices correlate to where along the urban density gradient land will convert to housing. Agricultural land is not unique to the urban fringe in the Phoenix area – since the location of farms initially depended on water availability, many still exist in fairly central parts of the region. We hypothesize that all else equal, residential conversions will take place nearer the downtown when oil prices are high due to the increased cost of intraurban transportation, while land conversion will favor the urban fringe when fuel prices are lower. This hypothesis is supported by a number of studies suggesting that higher fuel prices decrease various measures of urban sprawl. Dodson and Sipe (2007) contend that more automobile-dependent urban areas in Australia are disproportionately affected by rising fuel prices, while McGibany (2004) shows that U.S. metro areas with higher gasoline prices tend to have smaller urban footprints. Measuring Canadian cities, Tanguay and Gingras (2012) find that increased fuel prices increase the population in the city center while decreasing the proportion of low-density housing. Ortuño-Padilla and Fernández-Aracil (2013) echo this finding in Spain by comparing the construction rate of single-family homes versus apartments.

5.4 Results and Discussion

Survival curves are analyzed first (Figure 5.4) followed by a discussion of functional form. The main effects variables are then discussed, comparing results across three different spatial scales (Table 5.3). Temporal lag is then addressed (Table 5.4), followed by analysis of models which include interaction terms (Table 5.5). Full results can be found in Appendix A.

5.4.1 Survival Curves

Since the hazard ratios provided by a Cox regression and the odds ratio of a logistic functional form present instantaneous failure rates for the *entire* period, this can be complemented by analyzing survival over time graphically. For brevity, only 90m (middle) resolution results are shown in Figure 5.4. Residential conversions drop dramatically following 2006, which is reflected in the flattening survival curve after this point. Almost exactly one out of every six 90m cells that was in agricultural use in 1992 had converted to residential use by the end of 2013. Figure 5.4 also splits this survival probability curve by the side of town and soil quality category.

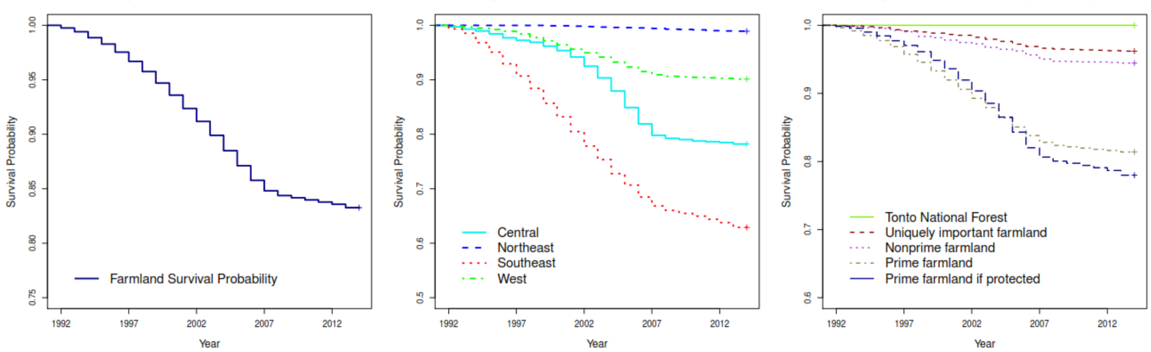

Figure 5.4: Survival curves by categorical variables

	360m				90m				60m			
Covariate	**Estimate**	*(std. error)*	**Hazard Ratio**	*(Wald $\chi 2$)*	**Estimate**	*(std. error)*	**Hazard Ratio**	*(Wald $\chi 2$)*	**Estimate**	*(std. error)*	**Hazard Ratio**	*(Wald $\chi 2$)*
Log Distance to CBD	-1.331	*(0.0325)*	0.264	*(1681**)*	0.2591	*(0.0072)*	1.296	*(1286**)*	0.2781	*(0.0056)*	1.321	*(2435**)*
Side of Town												
Central (vs. west)	-0.7647	*(0.0533)*	0.465	*(206**)*	0.345	*(0.0155)*	1.412	*(495**)*	0.2574	*(0.0114)*	1.294	*(510**)*
Northeast (vs. west)	-1.6751	*(0.1391)*	0.187	*(145**)*	-2.4286	*(0.1258)*	0.088	*(373**)*	-2.6756	*(0.1209)*	0.069	*(490**)*
Southeast (vs. west)	0.9532	*(0.0294)*	2.594	*(1053**)*	0.8815	*(0.0118)*	2.415	*(5572**)*	0.7321	*(0.0088)*	2.079	*(6905**)*
Soil Quality												
Tonto National Forest	-0.4778	*(0.9961)*	0.62	*(0)*	-4.458	*(13.4665)*	0.012	*(0)*	-3.8988	*(11.7712)*	0.02	*(0)*
Farmland of unique importance	-1.1319	*(0.0668)*	0.322	*(288**)*	-0.996	*(0.0275)*	0.369	*(1314**)*	-0.8459	*(0.0206)*	0.429	*(1681**)*
Not prime farmland	-0.6247	*(0.0797)*	0.535	*(61**)*	-0.8268	*(0.045)*	0.437	*(337**)*	-0.7891	*(0.0351)*	0.454	*(507**)*
Prime farmland if irrigated	0.2589	*(0.0282)*	1.296	*(84**)*	0.3006	*(0.0109)*	1.351	*(767**)*	0.3229	*(0.0081)*	1.381	*(1593**)*
Distance to nearest highway	0.0046	*(0.0021)*	1.005	*(5*)*	-0.0971	*(0.0019)*	0.907	*(2519**)*	-0.095	*(0.0015)*	0.909	*(4047**)*
Phoenix MSA Home Price Index	0.0065	*(0.0004)*	1.007	*(259**)*	0.0072	*(0.0001)*	1.007	*(3077**)*	0.0066	*(0.0001)*	1.007	*(4801**)*
AZ Alfalfa Hay Price	-0.0075	*(0.0006)*	0.993	*(159**)*	-0.0071	*(0.0002)*	0.993	*(1178**)*	-0.0071	*(0.0002)*	0.993	*(2182**)*
Cotton Price (A Index)	0.0036	*(0.0008)*	1.004	*(18**)*	-0.0012	*(0.0003)*	0.999	*(13**)*	-0.003	*(0.0002)*	0.997	*(146**)*
Crude Oil Price	-0.0219	*(0.0009)*	0.978	*(551**)*	-0.0188	*(0.0003)*	0.981	*(3432**)*	-0.0178	*(0.0002)*	0.982	*(5720**)*
Number of years since annexed	-0.0267	*(0.0019)*	0.974	*(198**)*	-0.018	*(0.0005)*	0.982	*(1122**)*	-0.0173	*(0.0004)*	0.983	*(2047**)*
Incorporated (vs. unincorporated)	0.8597	*(0.0431)*	2.362	*(398**)*	1.8834	*(0.0137)*	6.575	*(18804**)*	2.3976	*(0.0114)*	10.997	*(44478**)*
Converting cells	6,362				44,539				80,689			
Total cells	20,434				266,132				573,474			
Model *n*	378,526				5,581,796				12,155,056			
AIC	153,846				1,309,577				2,481,330			

**p<0.05, **p<0.001*

Table 5.3: Cox proportional hazards model results

5.4.2 Functional Form

The Cox proportional hazards model is considered to be the workhorse of survival analysis and its continuous specification is consistent with land change, which is not inherently discretized. However, using discretely specified data substantially decreases data needs (An and Brown 2008). Despite this incongruity, the Cox model's unspecified baseline hazard function and consideration of time-varying covariates are attractive properties while the EFRON continuous time approximation procedure in SAS facilitates its adaptation to discrete time observations (Allison 2010). In order to test the robustness of this adaptation, we also conduct estimation of the same-period main effects variables using a logistic regression and a complementary log-log regression (see Appendix A). While coefficient estimates vary slightly, the sign and significance test results – for all covariates across both 90m and 60m resolutions – do not differ from the Cox proportional hazards model[i]. Therefore the remainder of discussion will focus exclusively on Cox model results.

5.4.3 Cox Proportional Hazards Model Results

A first glance at parameter estimates and their associated hazard ratios in Table 5.3 indicates first that, no matter the scale, chi-squared values are high and nearly all variables are significant – regardless of spatial scale. This is simply a result of the high number of observations in the model. Due to the use of time-varying covariates, each cell is observed each year until it converts. For the 60m resolution models, 573,474 agricultural cells results in 12,155,056 observations in the regression. The Akaike Information Criterion (AIC) is used to compare across models (though, not across resolutions); a lower value indicates a better overall fit. Results are reported and discussed as hazard ratios, which indicate the covariate's effect on an observation's relative failure rate over the entire study period, evaluated using a chi-squared test.

5.4.4 Main Effects – Spatial Covariates

The effect of distance to downtown on the hazard of conversion is strongly negative at 360m resolution – an additional (log) mile from downtown decreases the hazard of conversion by 73.6%. While this appears consistent with a monocentric city assumption, it is largely an artifice of scale, as additional distance significantly increases the hazard of conversion in the 90m and 60m models – by about 30% per log mile. Outlying areas are more likely to convert. Scale-sensitivity is seen in the side-of-town variables as well: while these have some of the highest chi-squared values across all covariates, signs differ between coarse and finer resolutions. At 360m resolution, the hazard of conversion is highest for agricultural land in the southeast valley, followed by west, central, then northeast. While the southeast valley maintains the highest hazard of conversion at the finer resolutions (see Figure 5.4), the central area – consisting principally of the city of Phoenix – has a higher hazard of conversion than the west valley in these models. This can be attributed to the characteristics the city of Phoenix's farmland, which generally consisted of smaller farms whose size was less attractive to developers until the late boom period of the early 2000s. These developments were also less attractive to develop until later (despite their close proximity due to downtown) because they are in the Hispanic-majority neighborhood of South Phoenix (Kane et al. 2014c). Since these results demonstrate that 360m resolution is too coarse to pick up certain types of agricultural land in the region, subsequent interpretation of results will focus on the 90m and 60m models.

The contention that urbanization is most prevalent on the best farmland is not supported (see Figure 5.4). Farmland of unique importance has a 57% to 63% lower hazard of conversion than the third-best category which is farmland that is irrigated and flood-protected. The second-best soil – prime farmland that is irrigated but does not require flood protection – demonstrates the highest hazard of conversion to residential use. In fact, nonprime farmland and farmland of unique importance have fairly similar hazard ratios. This likely reflects the delineation of soil quality categories by the USDA, which defines farmland of unique importance region-by-region and includes specific high-value crops. The distinction that is more important may lie in the difference between development on agricultural land versus open desert. Following the state's

1980 Groundwater Management Act, a developer must demonstrate a 100-year supply of water before proceeding. This is easy on agricultural land which necessarily has existing water rights, though development on previously unoccupied desert requires a more difficult and expensive process to meet this requirement (Staudenmaier 2007).

5.4.5 Main Effects – Institutional Covariates

The effect of distance to the nearest limited-access freeway is a time-varying covariate since only 57% of the present-day freeway miles in the region had been built by 1992. The negative coefficient indicates that each additional mile from an existing freeway decreases the hazard of conversion by about 9%. Proximity to the transportation network is a positive attribute for new housing rather than a negative externality. This covariate's explanatory power is higher than that for the distance to the downtown area, which might be expected in a polycentric region like Phoenix. There may be somewhat of a concern over the endogeneity of freeway proximity to land conversion since this study considers distance to the nearest freeway that had already been built at the time in question. However, freeways are not necessarily built to serve existing population – developers are likely to acquire property and begin the process of homebuilding based on the expectation of future freeway construction. Since most area freeways were planned by the Arizona Department of Transportation in their original 1985 regional plan (2010), the point at which a developer realistically believes a highway will be built in time to serve newly-built housing is not entirely clear. As such, the question of the inductive, pre-construction effects of highway planning remains unexplored in this study.

The Phoenix area has a long history of competitive land annexation (Heim 2012). Results show that whether an agricultural parcel is within municipal boundaries is by far the strongest contributor to its hazard of conversion, ranging between a 657% to a 1099% increase in hazard ratio based on this covariate. However, the number of years elapsed since land was first included within municipal borders has a negative effect on the hazard ratio: an additional year elapsed since annexation reduced the hazard of conversion by 1.7% to 1.8%. In other words, newly annexed farmland is more likely to develop, suggesting that the processes of annexation and development go hand-in-hand as land developers negotiate with municipalities for inclusion and housing is quickly built. While the magnitude of this effect is smaller and likely varies from case to case, it clearly indicates that newly annexed land is seen more favorably for development. This is consistent with historical narratives of Phoenix which stress the importance of greenfield development and overall newness (Gober 2006) while highlighting the difficulty of infill growth in the region's core areas. In other words, older land becomes less desirable to convert.

5.4.6 – Main Effects – Market-Based Covariates

Interpretation of the hazard ratio of the price indices used in this study is straightforward and reflects the impact on conversion hazard of a one percentage point change in the indexed value. As expected, the metropolitan-level home price index has a positive and significant impact on the hazard of conversion. While its explanatory power (χ^2) is lower than some other covariates, it is consistent across all three resolutions: a one percentage point increase in home-price index increases the hazard of conversion by

0.7%. Conversely, and consistent with our hypothesis, an increase in cotton and alfalfa hay prices each decrease the hazard of conversion. A one percentage point increase in the regional price of alfalfa hay decreases conversion hazard by 0.7%. The relationship between cotton prices, which is traded on a global market, and conversion hazard operates in the same direction but is far weaker; a one percentage point increase decreases conversion hazard by 0.1% to 0.3%.

The relationship between crude oil price and conversion hazard was hypothesized to operate in two directions: positively as an agricultural input and negatively as a component of consumer/homebuyer spending. Oil price has a strong, negative coefficient – a one percentage point increase decreases the hazard of conversion by between 1.8% and 2.2% - the most of any price variable. This supports the hypothesis that oil price negatively impacts new housing development more than it increases a farmer's costs such that he is motivated to sell his land. Conversion hazard clearly decreases when oil prices are high.

5.4.7 – Lagged Main Effects

This study's dependent variable of land conversion is measured by the date on which a certificate of occupancy was granted for a new residence. While the decision to develop land must take place prior to this, how long before is unclear. A study of Michigan homebuilders suggested an average of eighteen months from development conception to completion (Vigmostad 2003). Given Arizona's year-round construction season and the rapid pace of Sunbelt housing growth during boom periods, this figure could be far lower locally.

	60m	*90m*	*60m*	*90m*	*60m*	*90m*
	Year-Of		**Prior Year**		**2 Years Prior**	
Phoenix MSA Home Price Index	1.007	1.007	1.004	1.005	1.003	1.003
AZ Alfalfa Hay Price	0.993	0.993	0.993	0.994	0.990	0.991
Crude Oil Price	0.982	0.981	0.98	0.979	0.975	0.974
AIC - Whole Model *(thousands)*	2,481	1,310	2,484	1,311	2,480	1,309

**all results significant at p<0.0001*

Table 5.4: Cox model hazards ratios for lagged price effects

The Cox regressions for 90m and 60m were re-estimated replacing current year values from MSA home price, cotton, alfalfa hay, and oil with previous year values and values from two years prior (see Table 5.4 or the full results in Appendix A). AIC scores indicate that model fit was weaker overall using a 1-year lag and slightly stronger using a 2-year lag. The effect of indexed home prices is strongest in the year-of and decreases back in time: present-day land conversion is more strongly related to present-day home prices rather than those from one or two years prior. This may indicate that new development is fairly quick to take shape. Alternatively it could indicate that developers are particularly savvy and are able to predict market conditions such that high home prices are aligned with when their product hits the market. This explanation seems even more plausible given that our outcome measure of land development only considers developments that were actually built – not the ones that failed to materialize. The negative effect of alfalfa hay prices on land conversion also shows a weaker effect farther back in time, but the decline is less pronounced than for home prices. In contrast, the negative impact on hazard ratio of crude oil prices is strongest two years prior to development – high crude oil prices two years ago decrease land conversion hazard today. This time lag is greater than that for home prices and can explain the slightly greater predictive power of the model which uses two-year-old price indices. A more targeted research design could investigate the timing of price and development further, though these results indicate a fairly rapid development process while highlighting the strong impact of an economic bellwether like oil price.

5.4.8 Interaction effects: Location and oil price, annexation and home price

An additional benefit of survival analysis is the ability to interact time-varying covariates such as price indices with spatial or institutional development drivers. A full set of interaction terms could increase predictive ability if the goal of a survival analysis were to predict future growth patterns. This study investigates two particular hypotheses of interest.

Crude Oil Price and Distance to CBD				**MSA Home Price Index and Years Since Annexed**			
		90m	*60m*			*90m*	*60m*
Dist. to CBD: overall hazard ratio		1.296	1.321	Years since annexed: overall hazard ratio		0.982	0.983
Hazard at Oil Price =	17 (min)	1.188	1.199	Hazard at Home Price =	121 (min)	0.997	0.998
	40	1.283	1.299		170	0.989	0.990
	60	1.372	1.394		220	0.982	0.982
	80	1.468	1.495		270	0.974	0.974
	96 (max)	1.549	1.581		322 (max)	0.967	0.966

Table 5.5: Hazard ratios for interaction effects

First, we hypothesized that conversion hazard would decrease in areas far from the CBD when oil prices were high. Homebuyers, aware that they would need to spend more on gasoline for a long commute, would tend to buy housing closer to the region's center. The main effects results (60m and 90m) indicated that conversion hazard was actually higher farther from the downtown and lower when oil prices were high. The coefficient of the interaction term, $\beta_{1,2}$ (the joint coefficient estimate of two covariates, i.e. $\beta_{1,2}X_1X_2$) is positive in both 90m and 60m models indicating reinforcing effects; however, the effects were not in the expected direction. Table 5.5 displays the overall hazard ratio of the distance to downtown variable along with the hazard ratio at a variety of different oil prices, calculated from $\beta_{1,2}$. As oil prices increase so does the hazard ratio for distance: high fuel prices actually increase the hazard of conversion of land farther from the city center. This is contrary to our transportation cost hypothesis and may represent a substitution effect: high gasoline prices decrease income, leaving homebuyers to search for cheaper housing at the urban fringe. While this would seem to increase transportation costs, it may not matter much for some: fringe homebuyers may be retirees who don't commute, they may also work in that part of the region, or they may be lower-income individuals don't have the credit needed to finance a bigger mortgage but can fairly easily spend more at the gas pump. Furthermore, destinations like shopping, employment, and recreation may be so concentrated in urban subcenters that the relationship between a residence and the region's core area is no longer important. This result contrasts with previous findings relating fuel price to urban form, which have varied in their outcome measure. While this study's use of Euclidean distance to downtown could be more nuanced with respect to polycentricity and an outcome metric of agricultural conversion omits other types of development, it does improve on previous work by examining within-city development decisions over a time horizon which saw drastic changes in oil price. Though this finding is reflective of the Phoenix area, its clarity and strength demonstrate that the perspective that higher oil prices will result in compact cities is far from a universal truth.

We also hypothesized that in booming times when home prices were high conversion hazard will increase on land that was recently annexed into a municipality. This would provide further evidence of endogeneity between annexation and development. The main effects result indicated that more elapsed time between annexation and land conversion decreases the hazard of conversion. Taking home prices into consideration, this effect is magnified: during housing price booms, the hazard of conversion based on elapsed time decreases, i.e. newly annexed land is more at risk. This provides further evidence that in booming times development is on even more recently annexed land, consistent with historical narratives of Phoenix.

5.5 Conclusions

This study investigates the conversion of agricultural land in the Phoenix metropolitan area from 1992 to 2013 using survival analysis. A variety of conclusions emerge about land conversion in Phoenix, the practice of modeling urban land-use change, and urban morphology more generally.

The Phoenix area is emblematic of fast-growing regions in the American Sunbelt, and some of its eccentricities are uncovered in this study. There is clearly no "death of Geography;" agricultural land that is farther out from the city center but with good highway access is at the highest risk of conversion. The Southeast subregion dominates, while the best soils are not necessarily at higher risk of conversion. Farmland within municipal boundaries – and in particular farmland that has recently been annexed into municipalities has an increased hazard of converting. This is consistent with the region's emphasis on newness and its history of competitive land consumption – by homebuyers and also municipalities in their desire to annex land. Evidence does suggest that development and annexation operate together – particularly during booms.

While much of this study's research design was tailored to the case of agricultural land in central Arizona, it demonstrates the usefulness of survival analysis in understanding urban growth and the benefits of including varying market conditions (in this case, both regional and global) into spatially-explicit modeling of land-use change. Future applications can focus on urban growth simulation and more targeted scenario planning. Predicting the impact of new highway construction, development impact fees, urban growth restrictions, or zoning alternatives on the hazard of land conversion could be easily handled using a Monte Carlo approach. While more complex land-use change platforms like UrbanSim are well-established and consist of many interacting sub-models, binary or multinomial outcome studies like this should be seen as a lightweight complement. However, they must be designed carefully. While this study did not find variation in results based on alternative functional forms, both spatial and temporal resolution impacted the results and must be chosen meticulously.

This study began with the fairly apparent hypothesis that varying market conditions have a large role in land conversion and urban morphological change. Empirical results confirm: while a number of factors show high statistical power, economic indicators – particularly the expected return on metro-level home construction and oil prices, an economic bellwether, are equally if not more important than spatial and institutional drivers of land development. Contrasting the strong effect of same-period housing prices with the lagged impact of oil prices on development highlights the difference between a global bellwether and the uniqueness of the process of land development, which may be fairly quick to take shape or speculative in nature. More generally it demonstrates the reach of global economic forces on land change decisions. Future research on urban land-use change should strive to include market indicators – including both those related to the housing industry such as home mortgage rates but also other national and global financial indicators. The recent global financial crisis demonstrated, rather starkly, the upward and downward connections between local markets for space and global markets for financial capital (Martin 2010).

Additionally, trends in cities such as preference for compact growth or fringe development should be researched thoroughly, positively, and across a wide variety of regions. The seemingly logical understanding that an increase in transportation costs will result in either compact growth or less fringe development is clearly incomplete. This study demonstrates that in a region characterized by fast growth and fairly cheap housing, higher oil prices could induce a substitution effect whereby new land is developed even farther toward the urban fringe. This has implications for understanding the role of proximity to a city center, which for retirees or suburban employees might mean very little. It also has implications for social equity: the ability for an individual to substitute transportation expense for housing expense is limited by access to credit. Finally, given concerns over the sustainability of Greenfield development and the policy interest in promoting compact growth and infill development, this study highlights the importance of understanding that developers' and homebuyers' response to market conditions, when measured in land-use changes, may not be as expected. This is a key finding for anyone interested in urban morphological change.

CHAPTER 6

CONCLUSIONS

This dissertation uses four individual research studies to investigate the historic, geographic microfoundations of Phoenix's urban morphology and the drivers of land development behind it. This conclusion first recapitulates the specific findings from these research studies then provides a discussion of their implications for urban research and urban theory. Finally, specific policy recommendations are considered.

6.1 Key Findings

Chapter 1 investigated how land-use heterogeneity and complementarity developed in historic Phoenix. The exodus from downtown following World War II was more closely related to residential parcels than retail decline, which is a commonly held contention of critics of today's high levels of vacancy in downtown Phoenix. This supports Sternleib's (prescient) 1963 contention that residential suburbanization isolated downtown retail which itself languished. Continual homogenization by land-use type is found to exist during this period as well; Phoenix did become more ordered from 1915-1963. Rather than wholesale land-use incompatibility, negative externalities were likely restricted to certain neighborhoods that remained near concentrating industrial land uses. Chapter 2 studies the meaning of fragmentation in discussions of urban sprawl, investigating land cover in Phoenix's census block groups based on when present-day structures were built. Observing within-lot rather than between-lot variation, newer-developing areas (which are not necessarily farther from the CBD) are less diverse and more homogenous in terms of land cover, reflecting the recent trend toward xeric landscaping and larger, more complex development styles that actually involve fewer cover types. In other words, areas developed since the 1990s are both more fragmented and more homogenous, though their landscaping may be more congruous with the surrounding desert ecosystem.

In comparing time periods directly before and after the global financial crisis of the late 2000s, Chapter 4 finds that boom-period housing was characterized by lower-cost, lower-density development on converted farmland in the interstices between regional subcenters. Following the collapse, development was more likely to be transit-adjacent, near commercial uses and public parks, on higher-valued land with higher-valued neighbors. This reflects a combination of evolving preferences for housing and changes in how housing is treated in the broader asset market. Some have termed this an "urban inversion" (Ehrenhalt 2012, Leinberger 2011, Plane 2013). Chapter 5 confirms the strong role of housing and agricultural market conditions in land conversion over a broader temporal and spatial extent, finding endogeneity in the relationship between municipal annexation and development and a strong role for oil prices in determining land development along an urban density gradient.

6.2 Implications for Urban Research and Urban Theory

This dissertation's chapters provide an implicit comparison of different spatial conceptions of a city. While Chapter 2 only covers a small fraction of present-day Phoenix, its rapid decline following World War II had long-lasting implications for the downtown core. Chapter 3 found so few block groups developed prior to the 1940s that empirical comparison with newer regions wasn't practical, highlighting the difficulty in drawing boundaries for space-time analysis. While Chapter 4 analyzes the municipality of Phoenix as a case study, analysis is best done on the level of a metropolitan area when possible – such as in Chapter 5 – as it represents a functional labor market area instead of a potentially arbitrary metropolitan border.

Phoenix's well-known polycentricity continually presents itself in this dissertation. Chapter 3 argues that development timing is more relevant than Euclidean distance for understanding land cover differentiation. However, Chapters 4 and 5 note that development based on distance to downtown is heavily scale-sensitive given the differences in parcel sizes across the region. While the fine-resolution results in Chapter 5 indicate that agricultural conversion (1992-2013) is more likely farther from the city center, Chapter 4 found evidence in more recent periods (2002-2006, 2006-2012) that either proximity or greater distance could be preferred. A more exhaustive study of commuter and household activity patterns – perhaps based on travel surveys or commute data – could relate a more nuanced concept of proximity to land-use change.

The practices of choosing an appropriate urban extent and conceptualizing intraurban location stress the need for local geographic knowledge even in quantitative analysis. Interpreting results and making decisions in processing fine-scaled geographic data could induce bias without at least some familiarity with the peculiarities of a region. This problem complicates interurban analysis of within-city patterns, as demonstrated by the resolution and spatial metric-induced systematic bias found in Burchfield et al.'s (2006) nationwide analysis of urban sprawl (Irwin and Bockstael 2007). Comparative studies involving several local experts such as York et al.'s (2011a) study of land fragmentation in five cities represent a partial solution. The increasing availability of parcel-level data from municipal governments and planning agencies provides consistent, fine-resolution information that can be compared across several regions at a time, though local history, physical topography, cross-municipal differences, and many other factors complicate even simple decisions like the delineation of space and time. Mirroring the spatial and temporal data-generating processes as well as using parcel-level data (Irwin 2010) are high on a list of best practices.

While this complicates empirical analysis, a theoretical hurdle to overcome is the over-reliance on the term "urban sprawl." Popularized in part by groups like the National Resources Defense Council (Benfield et al. 2001), the term is intended to summarize a number of concerns over urban morphology but lacks specificity and objectivity. In particular, Chapter 3 makes clear that the concepts of sprawl and fragmentation vary based on data resolution. Instead, focus should be placed on sprawl's constituent parts (see, e.g., Brueckner 2000) such as transportation, energy consumption, municipal infrastructure provision, landscape cover, and land use complementarity. A bricolage approach, such as Sampson's (2013) Project on Human Development in Chicago Neighborhoods or this dissertation on metropolitan Phoenix combines many related outcome measures in a particular region and combines empirical analysis with local geographic knowledge. The recent accumulation of academic publications on urban Phoenix has led to the informal creation of a desert school of urbanism which prioritizes sustainability in a fast-growing yet ecologically-fragile metropolis, analyzing land cover (e.g. Connors et al. 2012), environmental justice (e.g. Bolin et al. 2005), urban morphology (e.g. Gober and Burns 2002) and other outcome measures through a variety of social and physical science approaches.

A final, related component to local knowledge stressed throughout this dissertation is the importance of path-dependence and historical legacies in the creation of current and future urban spaces. This is seen in the variety of findings which relate land change and distance to downtown, and also the significant differences in land cover by development timing found in Chapter 3. Despite recent development in downtown Phoenix, its oversupply of vacant land and surface parking today are legacies of the postwar decline examined in Chapter 2. Municipal incorporation and the region's "annexation wars," which in Chapter 5 have a greater impact on agricultural land conversion than anything else, demonstrate that historical legacies can be institutionally as well as market-shaped.

Future work on methodological advancement should focus on validation of geographic statistical measures, policy counterfactuals, and a wider array of econometric outcome measures. While Chapter 2 uses random permutations to assess the significance of join-counts and land use transitions, assessing measures on simulated data could allay concerns over the reliability of results, especially across different regions. Studies such as Rey and Folch (2011) demonstrate this for particular indexed values. Chapters 4 and 5 use a binary dependent variable of developed versus undeveloped to investigate drivers of land change. As such Chapter 4's scope is limited to conclusions about single-family housing and Chapter 5's is limited to development on agricultural land. While this particular transition type is very prevalent in the study region, a multinomial approach like that of Levine (1998) is an extension that could simultaneously investigate multiple land change outcomes (single-family versus multifamily versus commercial, for example) while increasing predictive power. Inclusion of a mechanism for land prices (e.g., Wrenn and Irwin 2012) or a hedonic approach such as Golub et al. (2012) which uses home sales as a dependent variable can be a component of or a complement to the binary outcome metrics used in Chapters 4 and 5. A particularly attractive extension is the construction of policy counterfactuals, e.g., predicting the land development impact of a proposed new highway, development impact fees, or a zoning change. While UrbanSim and other coupled land use-transportation models are powerful and well-established (Waddell 2000), studies using a Cox regression plus a Monte Carlo simulation are highly adaptable and can be made lightweight enough to predict ranges and confidence intervals.

6.3 Policy Recommendations

The methods used in this dissertation hold high promise for future work that is more specifically tailored toward policy proposals, though a number of recommendations can be made based on these results. Chapter 4's findings on South Phoenix emphasize potential equity concerns surrounding land-use change and also provide some evidence of changing tastes such as nearby transit and public parks. The former should be scrutinized and the latter should be encouraged by favorable and unencumbered zoning designations that promote types of development that area residents increasingly desire. If market forces are sufficient to promote compact or infill growth, policy intervention in the form of subsidies may not be needed though it could help overcome encumbrances to investment in certain locations. Incentives, though, should be tailored toward public improvements rather than subsidizing development outright (Kane and Weber In Revision).

Chapter 5's findings are less optimistic though they do hint at a potential for successful intervention. A continual preference for land conversion in newly-annexed areas is inconsistent with compact growth objectives and indicates that Greenfield development may be disproportionately unencumbered, profitable, or actively promoted by municipal governments. Intervention such as transit-oriented zoning or credits for adaptive re-use of previously developed land could direct development capital toward areas with existing infrastructure and lower transportation costs while preserving agricultural or natural lands. Recent evidence suggests some of these efforts, at least in the Phoenix area, might be effective (Golub et al. 2012).

A counterintuitive finding from Chapter 5 is that land conversion hazard increases with distance from the downtown in times of high oil prices. While this merits further investigation using a more targeted research design, this finding should be a signal to policymakers that substitution of transportation expense for more accessible housing is not a given, particularly since this substitution would be more difficult for lower-income households. Especially as the “Fordist-era” suburban-style housing stock ages and decreases in price (Kamel 2014), its location relative to employment, shopping, and recreation needs to be considered by researchers and homebuyers alike as it could very well lead to increased transportation need despite higher fuel costs. This also supports the rationale of location efficient mortgages (Blackman and Krupnick 2001), which seek to facilitate the substitution of transportation cost with the (typically higher) cost of housing that requires less transportation.

REFERENCES

2010. Maricopa County, Arizona: Regional transportation plan. The National Academies: Transportation Research Board.

2012. Agricultural Property Manual. ed. P. T. Division. Phoenix, AZ: Arizona Department of Revenue.

2013. The Zoning Ordinances of the City of Phoenix. In *G-5777,* ed. C. o. Phoenix. Seattle, Washington: Code Publishing Company.

2014a. "A" Index. National Cotton Council of America.

2014b. National Resource Conservation Service Web Soil Survey. ed. U. S. D. o. Agriculture. Washington, D.C.

Aalbers, M. B. (2009) The sociology and geography of mortgage markets: Reflections on the financial crisis. *International Journal of Urban and Regional Research,* 33**,** 281-290.

Adams, J. S. (1970) Residential Structure of Midwestern Cities. *Annals of the Association of American Geographers,* 60**,** 37-62.

Agarwal, S., B. W. Ambrose, S. Chomsisengphet & A. B. Sanders (2012) Thy Neighbor ’s Mortgage: Does Living in a Subprime Neighborhood Affect One’s Probability of Default? *Real Estate Economics,* 40**,** 1-22.

Alberti, M. (2005) The effects of urban patterns on ecosystem function. *International Regional Science Review,* 28**,** 168-192.

Alberti, M. & J. Marzluff (2004) Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. *Urban Ecosystems,* 7**,** 241-265.

Allison, P. 2010. *Survival Analysis Using SAS*. Cary, NC: SAS Institute.

Allison, P. D. 1999. *Logistic Regression Using SAS: Theory and Application*. Cary, North Carolina: John Wiley & Sons.

Alonso, W. 1964. *Location and Land Use: Toward a General Theory of Land Rent*. Cambridge: Harvard University Press.

An, L. & D. G. Brown (2008) Survival analysis in land change science: Integrating with GIScience to address temporal complexities. *Annals of the Association of American Geographers,* 98**,** 323-344.

Anas, A., R. Arnott & K. A. Small (1998) Urban spatial structure. *Journal of Economic Literature,* 36**,** 1426-1464.

Arthur, W. B. 1988. Urban systems and historical path-dependence. In *Cities and Their Vital Systems,* eds. J. Ausubel & R. Herman. Washington, D.C.: National Academy Press.

Atkinson-Palombo, C. (2010) New housing construction in Phoenix: Evidence of "new suburbanism"? *Cities,* 27**,** 77-86.

Baatz, M. & A. Schape (2000) Multiresolution segmentation: An optimization approach for high quality multi-scale image segmentation. *Angewandte geographische informationsverarbeitung,* 12**,** 12-23.

Banzhaf, E. & R. Hofer (2008) Monitoring Urban Structure Types as Spatial Indicators With CIR Aerial Photographs for a More Effective Urban Environmental Management. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 1**,** 129-138.

Batty, M. 2005. *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge, Mass.: MIT Press.

Bausch, J. C., H. Eakin, S. Smith-Heisters, A. M. York, D. D. White, C. Rubiños & R. M. Aggarwal (2015) Development pathways at the agriculture‑urban interface: the case of Central Arizona. *Agriculture and Human Values*.

Bell, K. P. & E. G. Irwin (2002) Spatially explicit micro-level modelling of land use change at the rural-urban interface. *Agricultural Economics,* 27**,** 217-232.

Bell, N., N. Schuurman & S. M. Hameed (2008) Are injuries spatially related? Join-count spatial autocorrelation for small-area injury analysis. *Injury Prevention,* 14**,** 346-353.

Benfield, F. K., M. D. Raimi & D. D. T. Chen. 2001. *Once There Were Greenfields: How Urban Sprawl is Undermining America's Environment, Economy, and Social Fabric*. New York: Natural Resources Defense Council.

Benz, U. C., P. Hofmann, G. Willhauck, I. Lingenfelder & M. Heynen (2004) Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. *ISPRS Journal of Photogrammetry and Remote Sensing,* 58**,** 239-258.

Berke, P. R. (2002) Does Sustainable Development Offer a New Direction for Planning? Challenges for the Twenty-First Century. *Journal of Planning Literature,* 17**,** 21-36.

Blackman, A. & A. Krupnick. 2001. Location efficient mortgages: Is the rationale sound? Washington, D.C.: Resources for the Future.

Blaschke, T. (2010) Object based image analysis for repote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing,* 65**,** 2-16.

Bolin, B., S. Grineski & T. Collins (2005) The geography of despair: Environmental racism and the making of South Phoenix, Arizona, USA. *Research in Human Ecology,* 12.

Bolund, P. & S. Hunhammar (1999) Ecosystem services in urban areas. *Ecological Economics,* 29**,** 293-301.

Boone, C. G., E. Cook, S. J. Hall, M. L. Nation, N. B. Grimm, C. B. Raish, D. M. Finch & A. M. York (2012) A comparative gradient approach as a tool for understanding and managing urban ecosystems. *Urban Ecosystems,* 15**,** 795-807.

Bronska, M. 2011. Calculating development capacity - Understanding how to determine site yeild. Great Companies, LLC.

Brueckner, J. K. (2000) Urban sprawl: Diagnosis and remedies. *International Regional Science Review,* 23**,** 160-171.

Bruegmann, R. 2005. *Sprawl: A Compact History*. Chicago: University of Chicago Press.

Bunel, M. & E. Tovar (2013) Key Issues in Local Job Accessibility Measurement: Different Models Mean Different Results. *Urban Studies,* 51**,** 1322-1338.

Burchfield, M., H. G. Overman, D. Puga & M. A. Turner (2006) Causes of sprawl: A portrait from space. *Quarterly Journal of Economics,* 121**,** 587-633.

Butsic, V., D. J. Lewis & L. Ludwig (2011) An econometric analysis of land development with endogenous zoning. *Land Economics,* 87**,** 412-432.

CAP-LTER. 2012. Central Arizona-Phoenix Long-Term Ecological Research Land Use Classification. Tempe, AZ.

Carrion-Flores, C. & E. G. Irwin (2004) Determinants of residential land-use conversion and sprawl at the rural-urban fringe. *American Journal of Agricultural Economics,* 86**,** 889-904.

Carruthers, J. I. (2003) Growth at the fringe: The influence of political fragmentation in United States metropolitan areas. *Papers in Regional Science,* 82**,** 475-499.

Cho, S.-H., S. G. Kim & R. K. Roberts (2011) Values of environmental landscape amenities during the 2000–2006 real estate boom and subsequent 2008 recession. *Journal of Environmental Planning and Management,* 54**,** 71-91.

Cliff, A. D. & J. K. Ord. 1973. *Spatial autocorrelation*. London: Pion.

---. 1981. *Spatial processes : models and applications*. London: Pion.

Connors, J. P., C. S. Galletti & W. T. L. Chow (2012) Landscape configuration and urban heat island effects: assessing the relationship between landscape characteristics and land surface temperature in Phoenix, Arizona. *Landscape Ecology,* 28**,** 271-283.

Crump, J., K. Newman, E. S. Belsky, P. Ashton, D. H. Kaplan, D. J. Hammel & E. Wyly (2013) Cities Destroyed (Again) For Cash: Forum on the U.S. Foreclosure Crisis. *Urban Geography,* 29**,** 745-784.

Dacey, M. F. 1965. A review of measures of contiguity for two and k-color maps. In *Spatial Analyses: A Reader in Statistical Geography,* eds. B. J. L. Berry & D. F. Marble, 479-495. Englewood Cliffs: Prentice Hall.

Dietzel, C., M. Herold, J. J. Hemphill & K. C. Clarke (2005) Spatio-temporal dynamics in California's Central Valley: Empirical links to urban theory. *International Journal of Geographical Information Science,* 19**,** 175-195.

Dodson, J. & N. Sipe (2007) Oil Vulnerability in the Australian City: Assessing Socioeconomic Risks from Higher Urban Fuel Prices. *Urban Studies,* 44**,** 37-62.

Duany, A., J. Speck & M. Lydon. 2010. *The Smart Growth Manual*. New York: McGraw Hill.

Ehrenhalt, A. 2012. *The Great Inversion and the Future of the American City*. New York: Random House LLC.

Ewing, R., R. Pendall & D. Chen. 2002. Measuring Sprawl and Its Impact. Washington, D.C.: Smart Growth America.

Fischel, W. A. 2001. *The Homevoter Hypothesis*. Cambridge: Harvard University Press.

---. 2010. The evolution of zoning since the 1980s: The persistence of localism. In *Lincoln Institute of Land Policy conference*. Cambridge, Massachusetts: Social Science Research Network.

Florida, R. (2009) How the crash will reshape America. *The Atlantic Monthly,* 303.2**,** 44-56.

---. 2010. *The Great Reset*. New York: Harper Collins.

FRED. 2013. Privately Owned Housing Starts Authorized by Building Permits: 1-Unit Structures for Arizona. ed. U.S. Department of Commerce: Census Bureau. Federal Reserve Bank of St. Louis.

---. 2014. All-Transactions House Price Index for Phoenix-Mesa-Glendale, AZ (MSA) [ATNHPIUS38060Q]. ed. U. S. F. H. F. Agency. Federal Reserve Bank of St. Louis.

Frolking, S., T. Milliman, K. C. Seto & M. A. Friedl (2013) A global fingerprint of macro-scale changes in urban structure from 1999 to 2009. *Environmental Research Letters,* 8**,** 024004.

Gammage, G. 1999. *Phoenix in Perspective: Reflections on Developing the Desert*. Tempe, AZ: Herberger Center for Design Excellence, College of Architecture and Environmental Design, Arizona State University.

Garreau, J. 1991. *Edge City*. Doubleday: New York.

Glaeser, E. L. & J. Gyourko (2002) The impact of zoning on housing affordability. *National Bureau of Economic Research Working Paper,* 8835.

Gober, P. 2006. *Phoenix: Place Making and Community Building in the Desert*. Philadelphia: University of Pennsylvania Press.

Gober, P. & E. K. Burns (2002) The size and shape of Phoenix's urban fringe. *Journal of Planning Education and Research,* 21**,** 379-390.

Godfray, H. C., J. R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas & C. Toulmin (2010) Food security: the challenge of feeding 9 billion people. *Science,* 327**,** 812-8.

Golub, A., S. Guhathakurta & B. Sollapuram (2012) Spatial and temporal capitalization effects of light rail in Phoenix: From conception, planning, and construction to operation. *Journal of Planning Education and Research,* 32**,** 415-429.

Green, S. D. (1998) The search for a national land use policy: For the cities' sake. *Fordham Urban Law Journal,* 26.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. L. Redman, J. G. Wu, X. M. Bai & J. M. Briggs (2008) Global change and the ecology of cities. *Science,* 319**,** 756-760.

Grineski, S., B. Bolin & C. Boone (2007) Criteria air pollution and marginalized populations: Environmental inequity in metropolitan Phoenix, Arizona. *Social Science Quarterly,* 88**,** 535-554.

Guhathakurta, S. & R. J. Stimson (2007) What is Driving the Growth of New “Sunbelt” Metropolises? Quality of Life and Urban Regimes in Greater Phoenix and Brisbane-South East Queensland Region. *International Planning Studies,* 12**,** 129-152.

Hackworth, J. & N. Smith (2001) The changing state of gentrification. *Tijdschrift voor Economische en Sociale Geografie,* 92**,** 464-477.

Hall, E. (2007) Divide and sprawl, decline and fall: A comparative critique of Euclidean zoning. *University of Pittsburgh Law Review,* 68**,** 915-952.

Hart, J. F. (2001) Half a century of cropland change. *Geographical Review,* 91**,** 525-543.

Harvey, D. 2009. Opening speech at the Urban Reform Tent. In *World Social Forum*. Belem Para, Brazil.

Heim, C. E. (2012) Border wars: Tax revenues, annexation, and urban growth in Phoenix. *International Journal of Urban and Regional Research,* 36**,** 831-859.

Helm, C. (2001) Leapfrogging, urban sprawl, and growth management. *American Journal of Economics and Sociology,* 60**,** 245-283.

Herold, M., H. Couclelis & K. C. Clarke (2005) The role of spatial metrics in the analysis and modeling of urban land use change. *Computers, Environment and Urban Systems,* 29**,** 369-399.

Herold, M., X. Liu & K. C. Clark (2003) Spatial Metrics and Image Texture for Mapping Urban Land Use. *Photogrammetric Engineering and Remote Sensing,* 69**,** 991-1001.

Immergluck, D. (2010) Neighborhoods in the wake of the debacle: Intrametropolitan patterns of foreclosed properties. *Urban Affairs Review,* 46**,** 3-36.

Irwin, E. G. (2010) New directions for urban economic models of land use change: Incorporating spatial dynamics and heterogeneity. *Journal of Regional Science,* 50**,** 65-91.

Irwin, E. G., K. P. Bell & J. Geoghegan (2003) Modeling and Managing Urban Growth at the Rural-Urban Fringe: A Parcel-Level Model of Residential Land Use Change. *Agricultural and Resource Economics Review,* 32**,** 83-102.

Irwin, E. G. & N. E. Bockstael (2002) Interacting agents, spatial externalities and the evolution of residential land use patterns. *Journal of Economic Geography,* 2**,** 31-54.

--- (2007) The evolution of urban sprawl: evidence of spatial heterogeneity and increasing land fragmentation. *Proc Natl Acad Sci U S A,* 104**,** 20672-7.

Irwin, E. G. & J. Geoghegan (2001) Theory, data, methods: developing spatially explicit economic models of land use change. *Agriculture Ecosystems & Environment,* 85**,** 7-23.

Irwin, E. G., C. Jayaprakash & D. K. Munroe (2009) Towards a comprehensive framework for modeling urban spatial dynamics. *Landscape Ecology,* 24**,** 1223-1236.

Jacobs, J. 1961. *The Death and Life of Great American Cities*. New York: Random House.

Judd, D. R. & T. Swanstrom. 2008. *City Politics: The Political Economy of Urban America*. New York: Pearson.

Kallus, R. (2001) From Abstract to Concrete: Subjective Reading of Urban Space. *Journal of Urban Design,* 6**,** 129-150.

Kamel, N. (2014) Clandestine urbanization: reconstituting urban space in the margins of the Phoenix metropolitan area. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability***,** 1-12.

Kane, K., J. P. Connors & C. S. Galletti (2014a) Beyond fragmentation at the fringe: A path-dependent, high-resolution analysis of urban land cover in Phoenix, Arizona. *Applied Geography,* 52**,** 123-134.

Kane, K., J. Tuccillo, A. M. York, L. E. Gentile & Y. Ouyang (2014b) A spatio-temporal view of historical growth in Phoenix, Arizona, USA. *Landscape and Urban Planning,* 121**,** 70-80.

Kane, K. & R. Weber (In Revision) Municipal investment and property value appreciation in Chicago's Tax Increment Financing districts. *Journal of Planning Education and Research*.

Kane, K., A. M. York, J. Tuccillo, Y. Ouyang & L. Gentile (2014c) Residential development during the Great Recession: A shifting focus in Phoenix, Arizona. *Urban Geography,* 35**,** 486-507.

Keys, E., E. A. Wentz & C. L. Redman (2007) The Spatial Structure of Land Use from 1970‑2000 in the Phoenix, Arizona, Metropolitan Area. *The Professional Geographer,* 59**,** 131-147.

Kilian, L. & C. Park (2009) The impact of oil price shocks on the U.S. stock market. *International Economic Review,* 50**,** 1267-1287.

Kivell, P. 1993. *Land and the City*. New York: Routledge.

Klosterman, R. (1999) The What if? Collaborative planning support system. *Environment and Planning B,* 26**,** 393-408.

Knowles-Yanez, K., C. Moritz, J. Fry, C. L. Redman, M. Bucchin & P. H. McCartney. 1999. Historic Land Use Team: Phase I Report on Generalized Land Use. In

Central Arizona-Phoenix Long-Term Ecological Research Contribution No. 1. Tempe, AZ: Arizona State University Center for Environmental Studies.

Knox, P. L. (1991) The Restless Urban Landscape - Economic and Sociocultural Change and the Transformation of Metropolitan Washington, DC. *Annals of the Association of American Geographers,* 81**,** 181-209.

Kuffer, M. & J. Barros (2011) Urban Morphology of Unplanned Settlements: The Use of Spatial Metrics in VHR Remotely Sensed Images. *Procedia Environmental Sciences,* 7**,** 152-157.

Larson, K. L., D. Casagrande, S. L. Harlan & S. T. Yabiku (2009) Residents' Yard Choices and Rationales in a Desert City: Social Priorities, Ecological Impacts, and Decision Tradeoffs. *Environmental Management,* 44**,** 921-937.

Lee, S. H. 2011. The Impact of Mortgage Foreclosures on Existing Home Prices in Housing Boom and Bust Cycles: A Case Study of Phoenix, AZ. In *Urban and Regional Planning*, 341. Texas A&M.

Leinberger, C. B. 2008. *The Option of Urbanism: Investing in a New American Dream*. Washington, D.C.: Island Press.

--- (2011) The death of the fringe suburb. *The New York Times*.

Leinberger, C. B. & M. Alfonzo. 2012. Walk this way: The economic promise of walkable places in metropolitan Washington, D.C., ed. Brookings, 22. Washington, D.C.

Leslie, T. F. & B. Ó hUallacháin (2006) Polycentric Phoenix. *Economic Geography,* 82**,** 167-192.

Levine, J. (1998) Rethinking accessibility and jobs-housing balance. *Journal of the American Planning Association,* 64**,** 133-149.

Li, H., H. Campbell & S. Fernandez (2013) Residential segregation, spatial mismatch and economic growth across US metropolitan areas. *Urban Studies,* 50**,** 2642-2660.

Li, H. B. & J. F. Reynolds (1993) A New Contagion Index to Quantify Spatial Patterns of Landscapes. *Landscape Ecology,* 8**,** 155-162.

Li, X., S. W. Myint, Y. Zhang, C. Galletti, X. Zhang & B. L. Turner (2014) Object-based land-cover classification for metropolitan Phoenix, Arizona, using aerial photography. *International Journal of Applied Earth Observation and Geoinformation,* 33**,** 321-330.

Liu, X. & L. Lynch (2011) Do agricultural land preservation programs reduce farmland loss? Evidence from a propensity score matching estimator. *Land Economics,* 87**,** 183-201.

Longley, P. A. & V. Mesev (2000) On the measurement and generalisation of urban form. *Environment and Planning A*, 32**,** 473-488.

Luckingham, B. 1989. *Phoenix : The History of a Southwestern Metropolis*. Tucson: University of Arizona Press.

Martin, R. (2010) The local geographies of the financial crisis: From the housing bubble to economic recession and beyond. *Journal of Economic Geography,* 11**,** 587-618.

McDonnell, M. J. & A. K. Hahs (2008) The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. *Landscape Ecology*, 23**,** 1143-1155.

FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. 2.0.

McGibany, J. M. (2004) Gasoline prices, state gasoline excise taxes, and the size of urban areas. *Journal of Applied Business Research*, 20**,** 33-41.

Molotch, H. (1976) The city as a growth machine: Toward a political economy of place. *American Journal of Sociology,* 82**,** 309-330.

--- (1979) Capital and neighborhood in the Unites States - Some conceptual links. *Urban Affairs Review*, 14**,** 289-312.

Munroe, D. K., C. Croissant & A. M. York (2005) Land use policy and landscape fragmentation in an urbanizing region: Assessing the impact of zoning. *Applied Geography,* 25**,** 121-141.

Myint, S. W., E. A. Wentz, A. J. Brazel & D. A. Quattrochi (2013) The impact of distinct anthropogenic and vegetation features on urban warming. *Landscape Ecology,* 28**,** 959-978.

Nelson, R. H. 1977. *Zoning and Property Rights*. Cambridge: MIT Press.

Newburn, D. A. & P. Berck (2006) Modeling suburban and rural-residential development beyond the urban fringe. *Land Economics,* 82**,** 481-499.

Openshaw, S. & P. J. Taylor. 1981. The modifiable areal unit problem. In *Quantitative Geography: A British View,* eds. N. Wrigley & R. Bennett, 60-69. London: Routledge and Kegan Paul.

Ortuño-Padilla, A. & P. Fernández-Aracil (2013) Impact of fuel price on the development of the urban sprawl in Spain. *Journal of Transport Geography,* 33**,** 180-187.

Park, R. E., E. W. Burgess, R. D. McKenzie & L. Wirth. 1925. *The City*. Chicago, Ill.,: The University of Chicago Press.

Park, S. C., S.-W. Kwon & S.-J. Lee (2013) Participants in local zoning for multifamily housing development and decision delay: Transaction cost and heirarchical governance. *International Review of Public Administration,* 18**,** 167-197.

Peiser, R. (2001) Decomposing urban sprawl. *The Town Planning Review,* 72**,** 275-298.

Pfeiffer, D. & E. T. Molina (2013) The Trajectory of REOs in Southern California Latino Neighborhoods: An Uneven Geography of Recovery. *Housing Policy Debate,* 23**,** 81-109.

Phe, H. H. & P. Wakely (2000) Status, quality and the other trade-off: Towards a new theory of urban residential location. *Urban Studies,* 37**,** 7-35.

Pickett, S. T. A., W. R. Burch Jr., S. E. Dalton, T. W. Foresman, J. M. Grove & R. Rowntree (1997) A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems,* 1**,** 185-199.

Plane, D. 2013. Deconstructing the age dimension of the "Great Inversion". In *North American Regional Science Association*. Atlanta, GA.

Pontius, R. G. (2000) Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing,* 66**,** 1011-1016.

Pontius, R. G. & M. Millones (2011) Death to Kappa: Birth of quantity disagreement and allocation diagreement for accuracy assessment. *International Journal of Remote Sensing,* 32**,** 4407-4429.

Pontius, R. G., E. Shusas & M. McEachern (2004) Detecting important categorical land changes while accounting for persistence. *Agriculture Ecosystems & Environment,* 101**,** 251-268.

Putnam, R. D. 2000. *Bowling Alone: The Collapse and Revival of American Community*. New York: Simon and Schuster.

Reed, R. & S. Sims. 2008. *Property Development*. London: Routledge.

Rex, T. R. 2000. Population density in metropolitan Phoenix. 16. Tempe, AZ: Morrison Institute of Public Policy.

Rey, S. J. (2001) Spatial empirics for economic growth and convergence. *Geographical Analysis*, 33**,** 195-214.

Rey, S. J. & D. C. Folch (2011) Impact of spatial effects on income segregation indices. *Computers, Environment and Urban Systems,* 35**,** 431-441.

Rey, S. J., E. A. Mack & J. Koschinsky (2012) Exploratory Space-Time Analysis of Burglary Patterns. *Journal of Quantitative Criminology,* 28**,** 509-531.

Ross, A. 2011. *Bird on Fire: Lessons from the World's Least Sustainable City*. New York: Oxford University Press.

Sampson, R. J. 2013. *Great American City: Chicago and the Enduring Neighborhood Effect*. Chicago: University of Chicago Press.

Schafran, A. (2013) Origins of an urban crisis: The restructuring of the San Francisco Bay area and the geography of foreclosure. *International Journal of Urban and Regional Research,* 37**,** 663-688.

Schneider, A. & C. E. Woodcock (2008) Compact, Dispersed, Fragmented, Extensive? A Comparison of Urban Growth in Twenty-five Global Cities using Remotely Sensed Data, Pattern Metrics and Census Information. *Urban Studies,* 45**,** 659-692.

Scott, C. A., S. A. Pierce, M. J. Pasqualetti, A. L. Jones, B. E. Montz & J. H. Hoover (2011) Policy and institutional dimensions of the water‐energy nexus. *Energy Policy,* 39**,** 6622-6630.

Seto, K. C. & M. Fragkias (2005) Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics. *Landscape Ecology,* 20**,** 871-888.

Shrestha, M. K., A. M. York, C. G. Boone & S. Zhang (2012) Land fragmentation due to rapid urbanization in the Phoenix Metropolitan Area: Analyzing the spatiotemporal patterns and drivers. *Applied Geography,* 32**,** 522-531.

Siedentop, S. & S. Fina (2010) Monitoring urban sprawl in Germany: towards a GIS-based measurement and assessment approach. *Journal of Land Use Science,* 5**,** 73-104.

Smith, N. 1996. *The New Urban Frontier: Gentrification and the Revanchist City*. London: Routledge.

Staudenmaier, L. W. (2007) Between a rock and a dry place: The rural water supply challenge for Arizona. *Arizona Law Review,* 49.

Stehman, S. V., J. D. Wickham, J. H. Smith & L. Yang (2003) Thematic accuracy of the 1992 National Land-Cover Data for the eastern United States: Statistical methodology and regional results. *Remote Sensing of Environment*, 86**,** 500-516.

Steiner, F. R. & K. Butler. 2012. *Planning and Urban Design Standards*. Wiley.

Sternlieb, G. (1963) The Future of Retailing in the Downtown Core. *Journal of the American Institute of Planners,* 29**,** 102-112.

Talen, E. 2005. *New Urbanism and American Planning: The Conflict of Cultures*. London: Routledge.

--- (2011) The geospatial dimension in urban design. *Journal of Urban Design,* 16**,** 127-149.

---. 2012. *City Rules : How Regulations Affect Urban Form*. Washington, DC: Island Press.

Tanguay, G. A. & I. Gingras (2012) Gas price variations and urban sprawl: an empirical analysis of the twelve largest Canadian metropolitan areas. *Environment and Planning A,* 44**,** 1728-1743.

Taubenböck, H. & N. J. Kraff (2013) The physical face of slums: a structural comparison of slums in Mumbai, India, based on remotely sensed data. *Journal of Housing and the Built Environment,* 29**,** 15-38.

Taubenböck, H., M. Wiesner, A. Felbier, M. Marconcini, T. Esch & S. Dech (2014) New dimensions of urban landscapes: The spatio-temporal evolution from a polynuclei area to a mega-region based on remote sensing data. *Applied Geography,* 47**,** 137-153.

Theobald, D. M. (2001) Land-use dynamics beyond the American urban fringe. *Geographical Review,* 91**,** 544-564.

Thompson, W. A. (1977) On the treatment of grouped observations in life studies. *Biometrics,* 33**,** 463-470.

Tian, G. & J. Wu (2015) Comparing urbanization patterns in Guangzhou of China and Phoenix of the USA: The influences of roads and rivers. *Ecological Indicators,* 52**,** 23-30.

Tratalos, J., R. A. Fuller, P. H. Warren, R. G. Davies & K. J. Gaston (2007) Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning,* 83**,** 308-317.

Turner, B. L., A. C. Janetos, P. H. Verburg & A. T. Murray (2013) Land system architecture: Using land systems to adapt and mitigate global environmental change. *Global Environmental Change*, 23**,** 395-397.

Turner, M. G. (1989) Landscape Ecology - the Effect of Pattern on Process. *Annual Review of Ecology and Systematics*, 20**,** 171-197.

Turner, M. G., R. H. Gardner & R. V. O'Neill. 2001. *Landscape Ecology in Theory and Practice: Pattern and Process*. New York: Springer.

Turner, M. G., R. V. O'Neill, R. H. Gardner & B. T. Milne (1989) Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology,* 3**,** 153-162.

USDA. 2014. USDA National Agricultural Statistics Service: Price Received for Alfalfa Hay. University of Wisconsin - Madison.

VanderMeer, P. R. 2002. *Phoenix Rising : The Making of a Desert Metropolis*. Carlsbad, Calif.: Heritage Media Corp.

Vaughan, L., D. L. Chatford Clark, O. Sahbaz & M. M. Haklay (2005) Space and exclusion: Does urban morphology play a part in social deprivation? *Area*, 37**,** 402-412.

Verburg, P. H., Paul P. Schot, Martin J. Dijst, and A. Veldkamp (2004) Land use change modelling: current practice and research priorities. *GeoJournal,* 61**,** 309-324.

Vigmostad, K. E. 2003. Michigan real estate developer perspectives on development, sustainability, and nature: An autoethnography. In *Department of Resource Development*. Ann Arbor, MI: University of Michigan.

Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie & J. N. Van Driel (2001) Completion of the 1990s National Land Cover Data Set for the coterminus United States. *Photogrammetric Engineering & Remote Sensing,* 67**,** 650-662.

von Thunen, J. 1966. *Isolated State; an English edition of Der isolierte Staat*. New York: Pergamon Press.

Waddell, P. (2000) A behavioral simulation model for metropolitan policy analysis and planning: residential location and housing market components of UrbanSim. *Environment and Planning B: Planning and Design*, 27**,** 247-263.

White, M. J. (1978) Self-interest in the suburbs: The trend toward no-growth zoning. *Policy Analysis,* 4**,** 185.

Whyte, W. H. 1958. Urban Sprawl. In *The Exploding Metropolis,* ed. Fortune. Garden City, NY: Doubleday.

Wood, E. C., J. E. Lewis, G. G. Tappan & R. W. Lietzow. 1997. The Development of a Land Cover Change Model for Southern Senegal. In *Land Use Modeling Workshop, EROS Data Center*. Sioux Falls, SD.

Wrenn, D. H. & E. G. Irwin (2012) How do land use policies influence fragmentation? An econometric model of land development with spatial simulation. *Environmental Economics,* 3**,** 82-96.

Wu, F. L. & C. J. Webster (2000) Simulating artificial cities in a GIS environment: urban growth under alternative regulation regimes. *International Journal of Geographical Information Science,* 14**,** 625-648.

Wu, J. G. & O. L. Loucks (1995) From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. *Quarterly Review of Biology,* 70**,** 439-466.

York, A., J. Tuccillo, C. Boone, B. Bolin, L. Gentile, B. Schoon & K. Kane (2014) Zoning and Land Use: A Tale of Incompatibility and Environmental Injustice in Early Phoenix. *Journal of Urban Affairs,* 36**,** 833-853.

York, A. M., R. C. Feiock & A. Steinacker (2013) Dimensions of Economic Development and Growth Management Policy Choices. *State and Local Government Review,* 45**,** 86-97.

York, A. M. & D. K. Munroe (2010) Urban encroachment, forest regrowth and land-use institutions: Does zoning matter? *Land Use Policy,* 27**,** 471-479.

York, A. M., M. Shrestha, C. G. Boone, S. Zhang, J. A. Harrington, T. J. Prebyl, A. Swann, M. Agar, M. F. Antolin, B. Nolen, J. B. Wright & R. Skaggs (2011a) Land fragmentation under rapid urbanization: A cross-site analysis of Southwestern cities. *Urban Ecosystems,* 14**,** 429-455.

York, A. M., M. Shrestha, C. G. Boone, S. A. Zhang, J. A. Harrington, T. J. Prebyl, A. Swann, M. Agar, M. F. Antolin, B. Nolen, J. B. Wright & R. Skaggs (2011b) Land fragmentation under rapid urbanization: A cross-site analysis of Southwestern cities. *Urban Ecosystems,* 14**,** 429-455.

Zhang, S., A. M. York, C. G. Boone & M. Shrestha (2013) Methodological Advances in the Spatial Analysis of Land Fragmentation. *The Professional Geographer,* 65**,** 512-526.

Zhang, S. & K. Zhang. 2008. The study on trinary join-counts for spatial autocorrelation. In *Proceedings of the 8th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*. Shanghai, China.

APPENDIX A

SUPPLEMENTAL RESULTS FOR CHAPTER 5

PANEL A: COX PROPORTIONAL HAZARDS MODEL RESULTS											
	360m			90m				60m			
Covariate	**Estimate**	*(std. error)*	**Hazard Ratio**	**Estimate**	*(std. error)*	**Hazard Ratio**	*(Wald χ2)*	**Estimate**	*(std. error)*	**Hazard Ratio**	*(Wald χ2)*
Log Distance to CBD	-1.331	*(0.0325)*	0.264	0.2591	*(0.0072)*	1.296	*(1285.78**)*	0.2781	*(0.0056)*	1.321	*(2435.2**)*
Side of Town											
Central (vs. west)	-0.7647	*(0.0533)*	0.465	0.345	*(0.0155)*	1.412	*(495.03**)*	0.2574	*(0.0114)*	1.294	*(510.32**)*
Northeast (vs. west)	-1.6751	*(0.1391)*	0.187	-2.4286	*(0.1258)*	0.088	*(372.94**)*	-2.6756	*(0.1209)*	0.069	*(489.82**)*
Southeast (vs. west)	0.9532	*(0.0294)*	2.594	0.8815	*(0.0118)*	2.415	*(5571.5**)*	0.7321	*(0.0088)*	2.079	*(6904.7**)*
Soil Quality											
Tonto National Forest	-0.4778	*(0.9961)*	0.62	-4.458	*(13.4665)*	0.012	*(0.11)*	-3.8988	*(11.7712)*	0.02	*(0.11)*
Farmland of unique importance	-1.1319	*(0.0668)*	0.322	-0.996	*(0.0275)*	0.369	*(1314.07**)*	-0.8459	*(0.0206)*	0.429	*(1681.03**)*
Not prime farmland	-0.6247	*(0.0797)*	0.535	-0.8268	*(0.045)*	0.437	*(337.38**)*	-0.7891	*(0.0351)*	0.454	*(506.92**)*
Prime farmland if irrigated	0.2589	*(0.0282)*	1.296	0.3006	*(0.0109)*	1.351	*(767.45**)*	0.3229	*(0.0081)*	1.381	*(1593.02**)*
Distance to nearest highway	0.0046	*(0.0021)*	1.005	-0.0971	*(0.0019)*	0.907	*(2519.12**)*	-0.095	*(0.0015)*	0.909	*(4047.31**)*
Phoenix MSA Home Price Index	0.0065	*(0.0004)*	1.007	0.0072	*(0.0001)*	1.007	*(3077.34**)*	0.0066	*(0.0001)*	1.007	*(4801.43**)*
AZ Alfalfa Hay Price	-0.0075	*(0.0006)*	0.993	-0.0071	*(0.0002)*	0.993	*(1177.79**)*	-0.0071	*(0.0002)*	0.993	*(2182.09**)*
Cotton Price (A Index)	0.0036	*(0.0008)*	1.004	-0.0012	*(0.0003)*	0.999	*(12.69**)*	-0.003	*(0.0002)*	0.997	*(146.15**)*
Crude Oil Price	-0.0219	*(0.0009)*	0.978	-0.0188	*(0.0003)*	0.981	*(3431.69**)*	-0.0178	*(0.0002)*	0.982	*(5720.2**)*
Number of years since annexed	-0.0267	*(0.0019)*	0.974	-0.018	*(0.0005)*	0.982	*(1122.4**)*	-0.0173	*(0.0004)*	0.983	*(2047.48**)*
Incorporated (vs. unincorporated)	0.8597	*(0.0431)*	2.362	1.8834	*(0.0137)*	6.575	*(18803.96**)*	2.3976	*(0.0114)*	10.997	*(44478.07**)*
Converting cells	6,362			44,539				80,689			
Total cells	20,434			266,132				573,474			
Model *n*	378,526			5,581,796				12,155,056			
AIC	153,846			1,309,577				2,481,330			

**p<0.05, **p<0.001*

PANEL B: LOGISTIC REGRESSION RESULTS											
	360m			90m				60m			
Covariate	**Estimate**	*(std. error)*	**Odds Ratio**	**Estimate**	*(std. error)*	**Odds Ratio**	*(Wald χ2)*	**Estimate**	*(std. error)*	**Odds Ratio**	*(Wald χ2)*
Log Distance to CBD	-1.2585	*(0.0337)*	0.284	0.2595	*(0.0074)*	1.296	*(1226.08**)*	0.2747	*(0.0058)*	1.316	*(2278.85**)*
Side of Town											
Central (vs. west)	-0.3856	*(0.0486)*	0.471	0.6439	*(0.033)*	1.403	*(380.74**)*	0.6798	*(0.0311)*	1.293	*(477.86**)*
Northeast (vs. west)	-1.2519	*(0.1038)*	0.198	-2.1122	*(0.0943)*	0.089	*(502.2**)*	-2.2393	*(0.0906)*	0.07	*(610.5**)*
Southeast (vs. west)	1.2699	*(0.0396)*	2.465	1.1627	*(0.0321)*	2.357	*(1310.49**)*	1.1371	*(0.0306)*	2.043	*(1379.11**)*
Soil Quality											
Tonto National Forest	-0.3213	*(1.0038)*	0.725	-5.388	*(21.6094)*	0.005	*(0.06)*	-4.7161	*(17.6871)*	0.009	*(0.07)*
Farmland of unique importance	-1.1065	*(0.0672)*	0.331	-0.9995	*(0.0276)*	0.368	*(1314.37**)*	-0.8514	*(0.0207)*	0.427	*(1690.35**)*
Not prime farmland	-0.6042	*(0.0806)*	0.546	-0.824	*(0.0452)*	0.439	*(332.7**)*	-0.7901	*(0.0352)*	0.454	*(504.83**)*
Prime farmland if irrigated	0.2218	*(0.0289)*	1.248	0.2751	*(0.011)*	1.317	*(628.51**)*	0.2989	*(0.0082)*	1.348	*(1339.53**)*
Distance to nearest highway	-0.0068	*(0.0024)*	0.993	-0.0982	*(0.002)*	0.907	*(2445.7**)*	-0.0953	*(0.0015)*	0.909	*(3891.86**)*
Phoenix MSA Home Price Index	0.0084	*(0.0004)*	1.008	0.0076	*(0.0001)*	1.008	*(3359.05**)*	0.0069	*(0.0001)*	1.007	*(5183.15**)*
AZ Alfalfa Hay Price	-0.0051	*(0.0007)*	0.995	-0.0076	*(0.0002)*	0.992	*(1176.39**)*	-0.0079	*(0.0002)*	0.992	*(2315.65**)*
Cotton Price (A Index)	-0.0009	*(0.0009)*	0.999	-0.0011	*(0.0003)*	0.999	*(9.93*)*	-0.0026	*(0.0003)*	0.997	*(96.04**)*
Crude Oil Price	-0.0124	*(0.0013)*	0.988	-0.02	*(0.0005)*	0.98	*(1980.26**)*	-0.0199	*(0.0003)*	0.98	*(3568.04**)*
Number of years since annexed	-0.0236	*(0.002)*	0.977	1.8244	*(0.0138)*	6.199	*(17367.06**)*	-0.0166	*(0.0004)*	0.984	*(1822.2**)*
Incorporated (vs. unincorporated)	0.7842	*(0.0444)*	2.191	0.0152	*(0.0019)*	1.015	*(66.99**)*	2.3385	*(0.0114)*	10.366	*(41905.25**)*
Year	-0.0551	*(0.0053)*	0.946	-0.0168	*(0.0005)*	0.983	*(950.5**)*	0.0203	*(0.0014)*	1.021	*(216.33**)*
Converting cells	6,362			44,539				80,689			
Total cells	20,434			266,132				573,474			
Model *n*	378,526			5,581,796				12,155,056			
AIC	56,237			450,651				828,544			

**p<0.05, **p<0.001*

PANEL C: COMPLEMENTARY LOG-LOG MODEL RESULTS											
	360m			90m				60m			
Covariate	**Estimate**	*(std. error)*	-	**Estimate**	*(std. error)*	-	*(Wald χ2)*	**Estimate**	*(std. error)*	-	*(Wald χ2)*
Log Distance to CBD	-1.2253	*(0.0329)*		0.2547	*(0.0073)*		*(1210.65**)*	0.2703	*(0.0057)*		*(2252.86**)*
Side of Town											
Central (vs. west)	-0.3671	*(0.0481)*		0.6435	*(0.0329)*		*(381.47**)*	0.6789	*(0.0311)*		*(477.46**)*
Northeast (vs. west)	-1.2337	*(0.1034)*		-2.1015	*(0.0942)*		*(497.65**)*	-2.2294	*(0.0906)*		*(605.54**)*
Southeast (vs. west)	1.2409	*(0.0392)*		1.151	*(0.0321)*		*(1286.94**)*	1.1275	*(0.0306)*		*(1357.78**)*
Soil Quality											
Tonto National Forest	-0.3432	*(1.0019)*		-5.4116	*(21.6375)*		*(0.06)*	-4.761	*(17.8829)*		*(0.07)*
Farmland of unique importance	-1.0972	*(0.0667)*		-0.994	*(0.0274)*		*(1311.3**)*	-0.8464	*(0.0206)*		*(1685.68**)*
Not prime farmland	-0.5997	*(0.0798)*		-0.8206	*(0.045)*		*(332.17**)*	-0.7878	*(0.0351)*		*(505**)*
Prime farmland if irrigated	0.2176	*(0.0282)*		0.2715	*(0.0108)*		*(629.13**)*	0.2952	*(0.0081)*		*(1338.92**)*
Distance to nearest highway	-0.0066	*(0.0023)*		-0.0965	*(0.002)*		*(2423.8**)*	-0.0937	*(0.0015)*		*(3852.33**)*
Phoenix MSA Home Price Index	0.0082	*(0.0004)*		0.0075	*(0.0001)*		*(3327.81**)*	0.0068	*(0.0001)*		*(5141.06**)*
AZ Alfalfa Hay Price	-0.0049	*(0.0007)*		-0.0076	*(0.0002)*		*(1178.66**)*	-0.0078	*(0.0002)*		*(2325.33**)*
Cotton Price (A Index)	-0.0008	*(0.0009)*		-0.0011	*(0.0003)*		*(10.66*)*	-0.0026	*(0.0003)*		*(98.68**)*
Crude Oil Price	-0.0122	*(0.0012)*		-0.0198	*(0.0004)*		*(1974.84**)*	-0.0196	*(0.0003)*		*(3559.62**)*
Number of years since annexed	-0.0234	*(0.0019)*		-0.0167	*(0.0005)*		*(957.38**)*	-0.0165	*(0.0004)*		*(1829.64**)*
Incorporated (vs. unincorporated)	0.7732	*(0.0433)*		1.8092	*(0.0137)*		*(17392.04**)*	2.3258	*(0.0114)*		*(41897.87**)*
Year	-0.0543	*(0.0052)*		0.015	*(0.0018)*		*(66.67**)*	0.0201	*(0.0014)*		*(215.9**)*
Converting cells	6,362			44,539				80,689			
Total cells	20,434			266,132				573,474			
Model *n*	378,526			5,581,796				12,155,056			
AIC	56,271			450,752				828,667			

**p<0.05, **p<0.001*

PANEL D: COX MODEL RESULTS USING PRIOR YEAR PRICE INDICES						
	360m		90m		60m	
Covariate	**Estimate** *(std. error)*	**Hazard Ratio**	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*
Log Distance to CBD	-1.3811 *(0.0326)*	0.251	0.2769 *(0.0073)*	1.319 *(1427.8**)*	0.3014 *(0.0057)*	1.352 *(2781.15**)*
Side of Town						
Central (vs. west)	-0.7945 *(0.0534)*	0.452	0.3324 *(0.0155)*	1.394 *(460.01**)*	0.2415 *(0.0114)*	1.273 *(449.73**)*
Northeast (vs. west)	-1.6777 *(0.1391)*	0.187	-2.45 *(0.1258)*	0.086 *(379.52**)*	-2.7035 *(0.1209)*	0.067 *(500.12**)*
Southeast (vs. west)	0.9596 *(0.0294)*	2.611	0.8734 *(0.0118)*	2.395 *(5484.9**)*	0.7218 *(0.0088)*	2.058 *(6733.6**)*
Soil Quality						
Tonto National Forest	-0.5632 *(0.9964)*	0.569	-4.3853 *(13.4202)*	0.012 *(0.11)*	-3.8045 *(11.7141)*	0.022 *(0.11)*
Farmland of unique importance	-1.126 *(0.0668)*	0.324	-0.9908 *(0.0275)*	0.371 *(1300.65**)*	-0.8388 *(0.0206)*	0.432 *(1653.62**)*
Not prime farmland	-0.621 *(0.0797)*	0.537	-0.8172 *(0.045)*	0.442 *(329.65**)*	-0.7717 *(0.035)*	0.462 *(485.16**)*
Prime farmland if irrigated	0.2634 *(0.0282)*	1.301	0.2994 *(0.0109)*	1.349 *(760.44**)*	0.3222 *(0.0081)*	1.38 *(1584.71**)*
Distance to nearest highway	0.0123 *(0.0021)*	1.012	-0.1022 *(0.002)*	0.903 *(2710.08**)*	-0.1013 *(0.0015)*	0.904 *(4463.5**)*
Prior Yr. MSA Home Price Index	0.0035 *(0.0004)*	1.004	0.0047 *(0.0001)*	1.005 *(1046.95**)*	0.0043 *(0.0001)*	1.004 *(1628.49**)*
Prior Yr. Alfalfa Hay Price	-0.0052 *(0.0006)*	0.995	-0.0065 *(0.0002)*	0.994 *(966.27**)*	-0.0069 *(0.0002)*	0.993 *(2001.86**)*
Prior Yr. Cotton Price (A Index)	0.0017 *(0.0008)*	1.002	-0.0027 *(0.0003)*	0.997 *(66.79**)*	-0.0031 *(0.0002)*	0.997 *(159.42**)*
Prior Yr. Crude Oil Price	-0.0206 *(0.001)*	0.98	-0.0213 *(0.0003)*	0.979 *(3763.31**)*	-0.0205 *(0.0003)*	0.98 *(6558.48**)*
Number of years since annexed	-0.0273 *(0.0019)*	0.973	-0.0178 *(0.0005)*	0.982 *(1091.54**)*	-0.0169 *(0.0004)*	0.983 *(1944.74**)*
Incorporated (vs. unincorporated)	0.8714 *(0.043)*	2.39	1.8912 *(0.0137)*	6.627 *(18935.98**)*	2.4064 *(0.0114)*	11.094 *(44766.65**)*
Converting cells	6,362		44,539		80,689	
Total cells	20,434		266,132		573,474	
Model *n*	378,526		5,581,796		12,155,056	
AIC	154,143		1,311,046		2,483,870	

**p<0.05, **p<0.001*

PANEL E: COX MODEL RESULTS USING PRICE INDICES FROM TWO YEARS PRIOR						
	360m		90m		60m	
Covariate	**Estimate** *(std. error)*	**Hazard Ratio**	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*
Log Distance to CBD	-1.3687 *(0.0327)*	0.254	0.3014 *(0.0075)*	1.352 *(1636.82**)*	0.3289 *(0.0058)*	1.389 *(3223.88**)*
Side of Town						
Central (vs. west)	-0.793 *(0.0535)*	0.453	0.3069 *(0.0155)*	1.359 *(392.47**)*	0.2147 *(0.0114)*	1.24 *(356.01**)*
Northeast (vs. west)	-1.6734 *(0.1391)*	0.188	-2.4836 *(0.1258)*	0.083 *(389.99**)*	-2.7446 *(0.1209)*	0.064 *(515.45**)*
Southeast (vs. west)	0.9554 *(0.0294)*	2.6	0.8587 *(0.0118)*	2.36 *(5327.21**)*	0.7059 *(0.0088)*	2.026 *(6475.2**)*
Soil Quality						
Tonto National Forest	-0.5462 *(0.9965)*	0.579	-4.2825 *(13.3282)*	0.014 *(0.1)*	-3.6871 *(11.6297)*	0.025 *(0.1)*
Farmland of unique importance	-1.1221 *(0.0668)*	0.326	-0.9864 *(0.0275)*	0.373 *(1289.48**)*	-0.8354 *(0.0206)*	0.434 *(1640.82**)*
Not prime farmland	-0.6183 *(0.0797)*	0.539	-0.8103 *(0.045)*	0.445 *(324.23**)*	-0.7599 *(0.035)*	0.468 *(470.62**)*
Prime farmland if irrigated	0.2631 *(0.0282)*	1.301	0.298 *(0.0109)*	1.347 *(752.47**)*	0.3215 *(0.0081)*	1.379 *(1576.04**)*
Distance to nearest highway	0.0109 *(0.0021)*	1.011	-0.1091 *(0.002)*	0.897 *(2975.45**)*	-0.1089 *(0.0015)*	0.897 *(4985.11**)*
2 Yrs. Prior MSA Home Price Index	0.0017 *(0.0005)*	1.002	0.0033 *(0.0002)*	1.003 *(347.36**)*	0.003 *(0.0001)*	1.003 *(529.34**)*
2 Yrs. Prior Alfalfa Hay Price	-0.0056 *(0.0006)*	0.994	-0.009 *(0.0002)*	0.991 *(1603.92**)*	-0.0096 *(0.0002)*	0.99 *(3347.21**)*
2 Yrs. Prior Cotton Price (A Index)	0.0036 *(0.0009)*	1.004	-0.0007 *(0.0003)*	0.999 *(4.08*)*	-0.0011 *(0.0003)*	0.999 *(19.68**)*
2 Yrs. Prior Crude Oil Price	-0.0222 *(0.0011)*	0.978	-0.0261 *(0.0004)*	0.974 *(4031.86**)*	-0.0256 *(0.0003)*	0.975 *(7230.31**)*
Number of years since annexed	-0.0269 *(0.0019)*	0.973	-0.0171 *(0.0005)*	0.983 *(1002.04**)*	-0.0162 *(0.0004)*	0.984 *(1772.36**)*
Incorporated (vs. unincorporated)	0.8677 *(0.0431)*	2.381	1.8957 *(0.0138)*	6.657 *(18973.09**)*	2.4113 *(0.0114)*	11.148 *(44870.37**)*
Converting cells	6,362		44,539		80,689	
Total cells	20,434		266,132		573,474	
Model *n*	378,526		5,581,796		12,155,056	
AIC	154,075		1,309,427		2,480,142	

**p<0.05, **p<0.001*

PANEL F: COX MODEL WITH SELECTED INTERACTION TERMS						
	360m		90m		60m	
Covariate	**Estimate** *(std. error)*	**Hazard Ratio**	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*	**Estimate** *(std. error)*	**Hazard Ratio** *(Wald χ2)*
Log Distance to CBD	-1.2932 *(-1.2932)*	NA	0.115 *(0.0119)*	NA *(93.47**)*	0.1214 *(0.0092)*	NA *(174.73**)*
Crude Oil Price	-0.0129 *(-0.0129)*	NA	-0.0485 *(0.0021)*	NA *(532.71**)*	-0.0488 *(0.0016)*	NA *(961.5**)*
Dist_CBD*Crude Price	-0.0009 *(-0.0009)*	NA	0.0034 *(0.0002)*	NA *(198.7**)*	0.0035 *(0.0002)*	NA *(386.08**)*
Side of Town						
Central (vs. west)	-0.7654 *(-0.7654)*	0.465	0.3332 *(0.0156)*	1.395 *(456.95**)*	0.2475 *(0.0115)*	1.281 *(467.17**)*
Northeast (vs. west)	-1.6751 *(-1.6751)*	0.187	-2.4354 *(0.1258)*	0.088 *(375.07**)*	-2.6755 *(0.1209)*	0.069 *(489.8**)*
Southeast (vs. west)	0.9543 *(0.9543)*	2.597	0.8868 *(0.0118)*	2.427 *(5623.09**)*	0.7392 *(0.0088)*	2.094 *(7015.73**)*
Soil Quality						
Tonto National Forest	-0.4879 *(-0.4879)*	0.614	-4.5598 *(13.7022)*	0.01 *(0.11)*	-4.0283 *(12.0392)*	0.018 *(0.11)*
Farmland of unique importance	-1.1329 *(-1.1329)*	0.322	-0.9928 *(0.0275)*	0.371 *(1304.98**)*	-0.8416 *(0.0206)*	0.431 *(1663.14**)*
Not prime farmland	-0.6262 *(-0.6262)*	0.535	-0.8271 *(0.045)*	0.437 *(337.78**)*	-0.7932 *(0.035)*	0.452 *(512.56**)*
Prime farmland if irrigated	0.259 *(0.259)*	1.296	0.3044 *(0.0108)*	1.356 *(788.14**)*	0.3264 *(0.0081)*	1.386 *(1630.45**)*
Distance to nearest highway	0.0047 *(0.0047)*	1.005	-0.0938 *(0.0019)*	0.911 *(2452.57**)*	-0.0905 *(0.0015)*	0.913 *(3830.32**)*
Phoenix MSA Home Price Index	0.0068 *(0.0068)*	NA	0.0091 *(0.0002)*	NA *(3530.8**)*	0.0088 *(0.0001)*	NA *(5638.09**)*
Number of years since annexed	-0.0174 *(-0.0174)*	NA	0.0148 *(0.0016)*	NA *(88.03**)*	0.0176 *(0.0012)*	NA *(213.37**)*
Home Prices*Years since annexed	-0.00005 *(-0.00005)*	NA	-0.0002 *(0)*	NA *(447.08**)*	-0.0002 *(0)*	NA *(866.99**)*
AZ Alfalfa Hay Price	-0.0075 *(-0.0075)*	0.993	-0.0072 *(0.0002)*	0.993 *(1212.96**)*	-0.0072 *(0.0002)*	0.993 *(2255.88**)*
Cotton Price (A Index)	0.0036 *(0.0036)*	1.004	-0.0011 *(0.0003)*	0.999 *(11.2**)*	-0.0029 *(0.0002)*	0.997 *(142.09**)*
Incorporated (vs. unincorporated)	0.8509 *(0.8509)*	2.342	1.8479 *(0.0138)*	6.347 *(17978.99**)*	2.3588 *(0.0114)*	10.578 *(42809.66**)*
Converting cells	6,362		44,539		80,689	
Total cells	20,434		266,132		573,474	
Model *n*	378,526		5,581,796		12,155,056	
AIC	153,845		1,308,805		2,479,838	

**p<0.05, **p<0.001*

[i] The 360m resolution model has two covariates which are not consistent across the Cox, Logistic, and Complementary Log-Log models in sign. This can be seen in Appendix A. The distance to the nearest freeway and cotton price covariates have negative signs in the logistic and log-log models and positive signs in the Cox model. Since locational variables are shown to be unreliable using 360m due to the modifiable areal unit problem and cotton price has a relatively low test statistic value across all models, we do not feel these results impact our decision to rely on the Cox specification for analysis.