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Prices, Policies, and Place: What Drives Greenfield Development?

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Keywords: *Urban land-use change, Greenfield development, Urban Spatial Structure, Municipal Annexation, Freeway planning*

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ABSTRACT

While the recent global financial crisis heightened awareness of the linkages between global financial capital and urban spatial pattern, the timing of urban development – largely thought to be market driven – is not fully understood. Parcel-level studies of urban land-use change, which often use hazard models to investigate if and when development occurs, offer an opportunity to juxtapose the extent to which decisions to develop individual plots of farmland into housing are driven by market forces, the unique characteristics of the land and its intraurban location, or policies such as transportation infrastructure and municipal annexation. Using residential completion data in the Phoenix, Arizona region from 1992-2014, a period of dramatic commodity, fuel, and home price swings, and land cover imagery, we develop a parcel-level hazard model to gauge the relative impacts of market, policy, and place-based drivers of land change. We find limited evidence of induced development associated with freeway planning, that annexation and development are closely linked and moreso during economic booms, high fuel prices spur development in the region's core, and agricultural and urban land rents affect the timing of development. This study advances our understanding of development decision-making, policy impacts, and urban land-use change modeling and provides an empirical connection between local and global drivers of Greenfield development.

Keywords: *Urban land-use change, Greenfield development, Urban Spatial Structure, Annexation, Freeway planning*

Introduction

Urbanization, suburbanization, and land fragmentation 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, land development decisions are spatially disaggregated, involving individual landowners who decide whether and when to convert parcels of land from one use to another (Irwin, 2010). 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). The recent global financial crisis demonstrated how the increasingly financialized industry of residential development directly impacts neighborhoods in terms of foreclosures and stalled (Crump et al., 2013; Immergluck, 2010; Kane, York, et al., 2014). Put differently, urban spatial pattern is thought to be sensitive to booms, busts, and macroeconomic shocks, and perhaps increasingly so. Meanwhile 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 (Adams, 1970; Kane, Connors, & Galletti, 2014). Spatially disaggregated land change models are yet to specifically compare global and regional-level financial indicators with spatial and institutional change drivers such as intraurban location, soil quality, and municipal annexation. In this study, we focus on how the housing and agricultural commodities markets impact land change, while comparing against policy-based and place-based drivers of development.

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 (Benfield, Raimi, & Chen, 2001). 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 (Godfray et al., 2010; Jeer, 1997). Specific policies aimed at preserving farmland have been proposed and implemented by government entities (Liu & 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 its overall effect (Butsic, Lewis, & Ludwig, 2011; Talen, 2012; York & Munroe, 2010). Large-lot zoning at the urban fringe in combination with fragmented municipal boundaries have been identified as causes of an expanded urban footprint which is often characterized as urban sprawl (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 (Leinberger & Alfonzo, 2012; Peiser, 2001).

Spatially disaggregated models of land change (i.e. those conducted at the level of individual land parcels) have investigated critiques of urban sprawl, evolving preferences for neighboring land, and specific zoning policies by linking the development of parcels across a city to their locational attributes, regulations on their use, and other factors (Irwin & Bockstael, 2002; Kane, York, et al., 2014; Newburn & Berck, 2006; Seto & Fragkias, 2005). Survival analysis, also known as hazard modeling, is a parsimonious means of capturing the time-varying aspects of development trajectories to understand longer-term trends. Land change studies using survival analysis have successfully related time-varying factors like population density or regulatory costs to the length of time before a unit of land converts (An & Brown, 2008; Wrenn & Irwin, 2012). We investigate the development of housing on agricultural land in the Phoenix, Arizona, USA metropolitan area during a period of tremendous swings in agricultural commodity, housing, and oil prices allowing us to disentangle the relationships between greenfield development prices, policies, and place. Using remotely-sensed imagery to identify agricultural land, a Cox hazard model identifies if and when a unit of agricultural land experienced a conversion to residential use at any time between January 1992 and December 2014.

Land Conversion Model

The conversion of agricultural land is a complex process involving numerous actors, policies, and decisions. 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 and development. 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, high returns ensured that the requisite title transfers, zoning changes, platting, and construction that constitute this process took place quickly and efficiently.

Market factors and policies both impact the speed and complexity of the process. In this region, as in much of the United States, land that is being farmed is assessed based on agricultural rents resulting in a very low property tax burden for the owner. In contrast, vacant land that is not in production is assessed based on its potential for income-producing urbanized uses such as housing, resulting in a tax burden several times higher (*Agricultural Property Manual*, 2012). In Arizona it has been common practice for developers or investors to purchase property and lease it back to a farmer in order to maintain tax benefits while maintaining the flexibility to build housing should market conditions improve. In this region, agricultural zoning is not used to slow development pressure and is easy to change. A recent study of farmers and other stakeholders (Bausch et al. 2015) overwhelmingly confirmed the perspective that expected returns – rather than land conservation or preservation policy – were the primary impetus for sale decisions.[i]

This study abstracts the transaction between farmer and developer and models only one actor: a landowner who can choose to convert a unit of farmland into housing. Arnott and Lewis (1979) first propose a model for when the owner of vacant land at the urban fringe should convert it to urban use. Capozza and Helsley (1989) propose an optimal timing model for agricultural land conversion in which the landowner's profit maximizing decision is to choose a date of conversion t^* which depends on agricultural rents, the cost of conversion, the value of accessibility, and the value of expected future rent increases. A recent adaptation using discrete units of land i is found in Wrenn and Irwin (2012):

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

where r is the discount rate, A is the value of agricultural rents, H is the rent that can be expected from housing, and C is the 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 conditions of the local housing market, agricultural commodities markets, and other regional and global conditions at the time of conversion. $H(x_{it})$ 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 across the study area in conversion costs of a land parcel.

Survival analysis has been recognized as a parsimonious method for understanding the spatially and temporally varying covariates affecting the landowner's conversion decision in Equation (1). The probability of land surviving in agricultural use beyond time t can be given as the survival function, $S(t)$:

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

where $h(x)$ refers to the hazard of land conversion, which can be thought of as a failure rate that is intrinsic to each individual i. In land change science, hazard refers to the cumulative risk of land conversion over the study period.

While a landowner's decision to convert farmland into housing operates continuously, the empirical specification is complicated because thousands of units of agricultural land are continuously at risk of conversion. In addition, conditions impacting hazard change over time such as the proximity of a land parcel to a freeway network when new roads are being built. The reality in land change science is that continuous information is unlikely to be available or manageable for every parcel of land over a long study period. Following An and Brown (2008), a discrete-time model such as a logit or complementary log-log specification can be used to approximate continuous time process when the temporal resolution is fairly coarse – in this study land parcel characteristics are observed yearly. These discrete models converge to the continuous-time, semi-parametric Cox hazard model as the time interval decreases and ties can be efficiently estimated (Allison, 2010; Thompson, 1977). 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. Strictly speaking, the Cox model relies on an assumption of proportional hazards – $h_i(t)$ is not directly observed or fit to a parametric baseline hazard function. Instead, partial likelihood estimation is used to compare the ratio of the hazard for individuals i and j as demonstrated below:

(4) $\frac{h_i(t)}{h_j(t)} = exp\{\beta_1(x_{i1} - x_j) + \cdots + \beta_k(x_{ik} - x_{jk})\}$

Estimates are efficient and asymptotically normal with minimal efficiency loss even in the case of tied data (Thompson, 1977). A challenge arises in land change applications since many factors impacting land conversion probability vary over the study period, which was recognized by Irwin and Bockstael (2002). One example of these time-varying covariates (TVCs) is a parcel's distance to the freeway network, which can decrease as new freeways are built, while economic conditions – a function of time – can be handled similarly. Allison (2010) argues that the assumption of proportional hazards can be relaxed such that time varying covariates can be included, changing equation (3) slightly to:

(5) $Log\ h_i(t) = \alpha(t) + \beta X_{i1} + \gamma X_{i2}(t)$

Where β represents coefficients for time-invariant covariates and γ represents coefficients for time-varying covariates. Practically, this is achieved by discretizing time as proposed by An and Brown (2008) and Allison (2010). The tradeoff is data intensiveness: each observation, including the status of each time-varying covariate, must be observed in each time period – annually, in this study.

In addition to the Cox hazard model, which is the most common choice for survival analysis, land change applications using survival analysis have used inherently discrete-time specifications including a binary logit (Beck, Katz, & Tucker, 1998; Wrenn & Irwin, 2012) and a complementary log-log (An and Brown 2008). As a robustness check, we estimate these models alongside the Cox model, which is typically the preferred choice. In any of these cases, rather than assuming a parametric baseline hazard function $\alpha(t)$ such as a Weibull or exponential distribution, we allow time-varying market indicators including metropolitan-area wide housing prices, mortgage rates, agricultural commodity prices, and fuel price to characterize the hazard that each unit of land will convert. In doing so, we analyze the response of land developers to fluctuating price trends over time as well as their response to other factors that vary over space, such as annexation policies, freeway access and freeway planning, farmland quality, and distance to downtown.

Study Area and Data

The study area is Maricopa County, Arizona. The county contains nearly all of the population and developed land in the Phoenix metropolitan area. 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, supported by increasingly sophisticated and expensive water management infrastructure (Balchin, 1988) which adds to its already sensitive desert ecosystem and microclimatic effects (Connors, Galletti, & Chow, 2012). By 1934, the County's urbanized area totaled 8,557 acres and by 2010 had swelled to nearly 400,000 acres (CAP-LTER, 2012), placing it 12th among US urban areas. While the region's 2010 population of 3.9 million ranks it as the 14th largest metropolitan area, this follows a meteoric increase from 1950, when the city of Phoenix was ranked 99th with a population of

106,818. 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.

No previous survival analysis of land conversion of which we are aware considers an area with this large a spatial and temporal extent. Almost all previous studies use sampled data such as An and Brown's (2008) 4% random sample of parcels in southeastern Michigan, a subset of developable land such as Irwin and Bockstael's (2002) 4,509 parcels in rural Maryland which could accommodate at least five homes, or a fairly small universe such as Wrenn and Irwin's (2012) 3,844 undeveloped subdivisions in exurban Maryland. In contrast, this study covers all agricultural land in the 4th most populous county in the United States – a land area equivalent to roughly 2.3 million homes which experienced approximately ¼ million new homes built from 1992-2014. While most previous studies are concerned specifically with the ability of growth management plans to restrict rural land conversion, the Arizona case illustrative of the massive scale of residential development occurring in booming areas worldwide. Guhathakurta and Stimson (2007) discuss the primacy of these Sunbelt urban regimes characterized by desirable living conditions and pro-growth policies. More generally, Glaeser and Tobio (2007) find strong correlations between January temperatures and economic growth, but more lasting positive correlations between warm climates and housing supply growth. Finally, a widely accepted tenet about global urbanization is that it will increasingly take a suburban form – the model of which is largely the American experience of single-family homeownership (Leichenko & Solecki, 2015). Phoenix – with its seemingly unfettered trajectory toward growth and dispersal amidst environmental uncertainty – can be particularly informative for other world regions.

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. While the use of NLCD imagery has been critiqued for its accuracy in humid regions with high levels of tree cover (Irwin & Bockstael, 2007; Stehman et al., 2003), desert regions like Arizona do not suffer from these problems (Shrestha et al., 2012). 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, which is heavily irrigated resulting in an especially stark signature against the arid desert backdrop. Using ArcGIS software a lattice, or grid is constructed on top of the entire raster imagery and whether or not each grid cell contained agricultural land was identified[ii]; three cell sizes were generated enabling robustness checks. Cells were identified as either agricultural land or not; the latter are excluded from the analysis (see Figure 1).

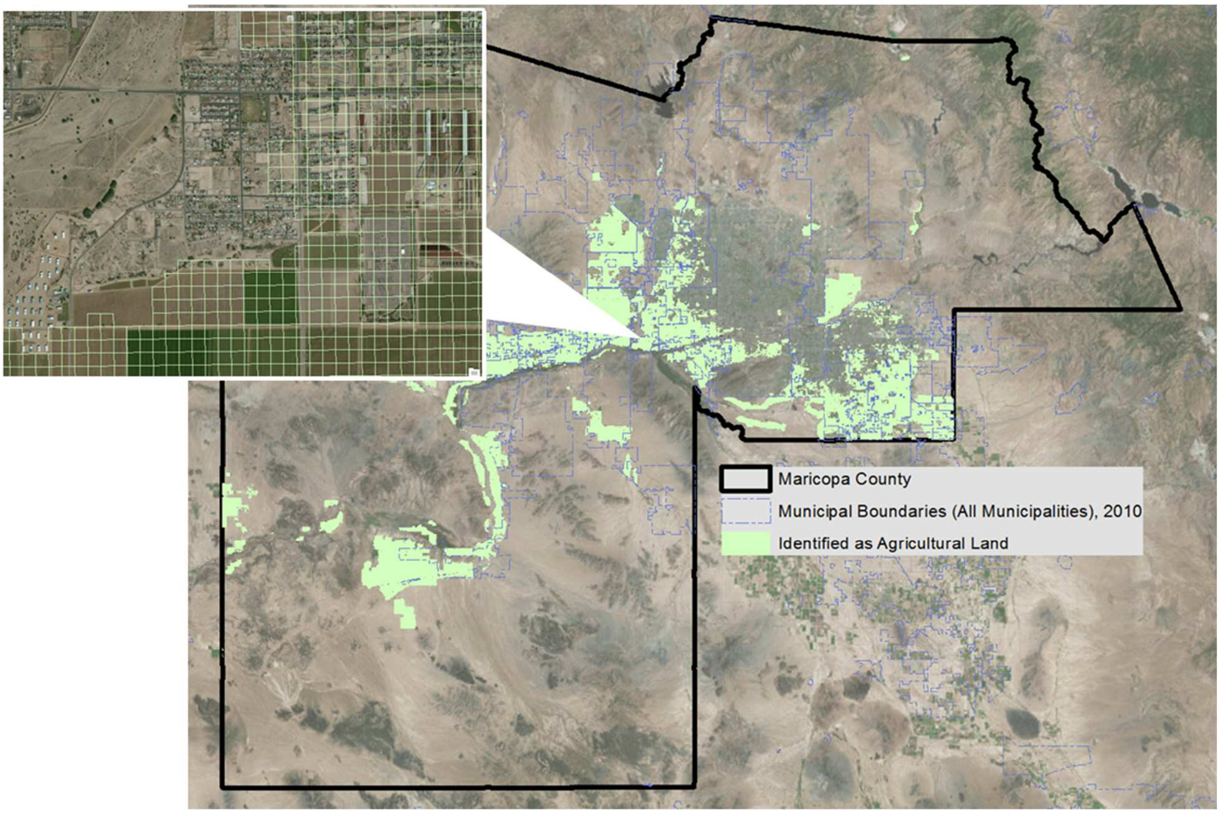

Figure 1: Agricultural Land Identified by NLCD, 1992 (90m resolution)

New residential construction and dependent variable

The Maricopa Association of Governments (MAG), the Phoenix area's regional planning agency, 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. 594,150 residential completions were recorded between January 1, 1992 and December 31, 2014.

Observations in this analysis are grid cells of agricultural land and the discrete dependent variable is whether and when an agricultural conversion was recorded on that grid cell. This was achieved by spatially joining residential completions to the grid cells in ArcGIS software. While studies often use individual land parcels in order to preserve the connection between parcel characteristics and the decision to develop (see, e.g., Irwin, 2010; Kane, Tuccillo, et al., 2014), analyzing agricultural conversions over a long time period becomes complicated since parcel boundaries change frequently, particularly during periods of subdivision and development. While using artificial units of land comes at a cost of modeling economic behavior directly, it affords the ability to standardize land boundaries over time while using municipal occupancy certificates reflects the culmination of the development process: when a home is considered habitable. It also avoids the need to sample, improving statistical inference.

An additional complication in using grid cells is that the size of both farms and new homes varies and an appropriate resolution is not readily apparent. Low-density residential development in the United States is typically considered to be 4 units per acre, or 10,890 ft^2 (Steiner & 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 (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 2 shows a neighborhood in Avondale, Arizona with residential conversions and the agricultural land lattice at all three grid cell sizes (resolutions): 360m, 90m, and 60m and Table 1 provides statistics based on these resolutions. Both 60m and 90m resolutions each contain roughly the number of homes expected based on region-wide size averages, indicating that these scales better reflect conversion from the perspective of farmland converting to individual homes – the goal of this study. 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 48 homes. These coarse resolution cells are closer in size to subdivisions—master-planned developments of homes which are common in the Phoenix area and in other studies of residential land development (e.g., Abbott & Klaiber, 2010), which may capture the "first movers" of development though these are subdivided over time to maximize per-unit land value. This analysis is conducted using 60m, 90m, and 360m cells as a robustness test.

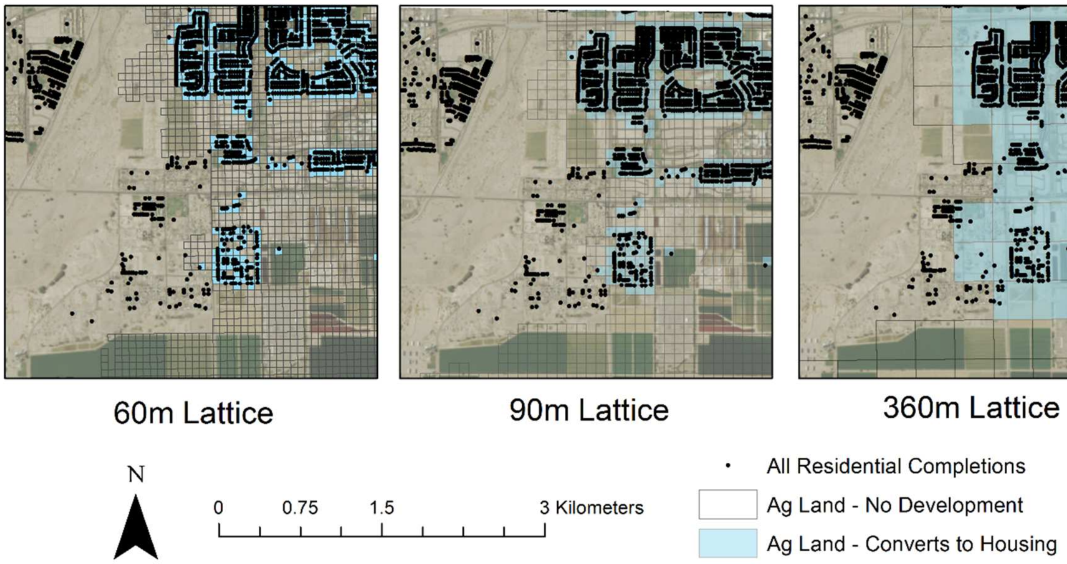

Figure 2: A Neighborhood in Avondale, Arizona at Three Resolutions

TABLE 1: AGRICULTURAL ("ag") CELL CONVERSION AT MULTIPLE RESOLUTIONS

Resolution	Number of ag cells, 1992	Number of ag cells that convert to residential, 1992-2014 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	19,188	6,044	32.0	112	47.87	289,302
90m	265,892	45,422	2.0	7	5.85	265,759
60m	573,029	82,244	0.9	3	3.15	259,387

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

Spatial covariates

Urban economic theory posits a tradeoff between access and space in the determination of where people choose to live (Anas, Arnott, & Small, 1998; Phe & 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 the emergence of multiple subcenters of concentrated activity – particularly in Phoenix (Leslie & 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 into several sub-regions: west, southeast, northeast (principally the city of Scottsdale) and central (principally the city of Phoenix). Southeast, central, and northeast dummy variables are considered relative to the reference category: west.

Both agricultural rent and development costs are impacted by 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 built near fertile areas (Benfield, Raimi, & Chen, 2001). However this is largely an issue of perception since the high price of 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, *National Resource*

Conservation Service Web Soil Survey, 2014). 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.[iii]

Policy 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 2014, this had increased to 461 miles (authors' calculation). Freeway development has been largely a product of long-range planning: MAG's 1985 regional plan laid the framework for the future freeway map, which has been constructed in phases as population grows and funding is available ("Maricopa County, Arizona: Regional transportation plan," 2010). Freeway access is considered extremely important to real estate development generally, and in Phoenix in particular (Tian & 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 capture the possibility of induced development resulting from a planned freeway, we include the Euclidean distance from each cell to the nearest freeway as of the end of the study period, 2014, at which time nearly all of the regional plan had been built out. However, a planned freeway is not a certain indicator of accessibility. In order to account for the changing freeway map over the study-period, we also include a time-varying covariate containing the distance from the cell to the nearest highway that had been built by that year. The anticipated negative coefficient on either variable would indicate that proximity to an existing or a planned 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, York, et al. (2014) 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. Like most of the country there is fairly limited coordination in zoning codes and policies (Dowall, 1989; Esparza & Carruthers, 2000) and each of the region's 26 municipalities have adopted different zoning codes, within and across the jurisdictions these codes are operationalized differently (York & Munroe, 2013). Due to the difficulty in constructing a consistent variable across the jurisdictions, as well as the relative ease of changing the zoning within the region, we opted not to include this policy variable; instead we focused on annexation, which captures the shift from unincorporated county land to city land with requisite provisioning of services for households, including water, which is especially important in this desert landscape.

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 real estate booms using an interaction term. In other words, is there a joint positive effect of the recentness of annexation and high home prices?

Housing market

Numerous land change studies have considered the impact of zoning, soil quality, transportation access, and intraurban location. This paper's main contribution, largely due to the ability of survival analysis to compare spatially and temporally-varying covariates, is to investigate the impact of market conditions on the decision to develop land using a spatially disaggregated model. 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 Housing Finance Agency (FHFA) to measure the variation in regional housing market conditions over the study period (FHFA, 2014)[iv]. 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. Additionally, we compare the impact of mortgage interest rates on land conversion. Low mortgage rates are expected to result in more home lending and therefore more land conversion to fulfill the resulting demand for housing. Low mortgage rates are often implicated in the oversupply of housing during the building boom of the early 2000s – we expect an inverse relationship between interest rates and land conversion. (FHFA, 2015).

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 crops 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 (*"A" Index*, 2014) 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 for this 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 & 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. National-average gasoline prices from the U.S. Energy Information Administration (EIA, 2015) are compared against oil prices –

while they are expected to be similar, they have a clearer relationship to transportation cost. A comparison of prices over the study period can be found in Figure 3.

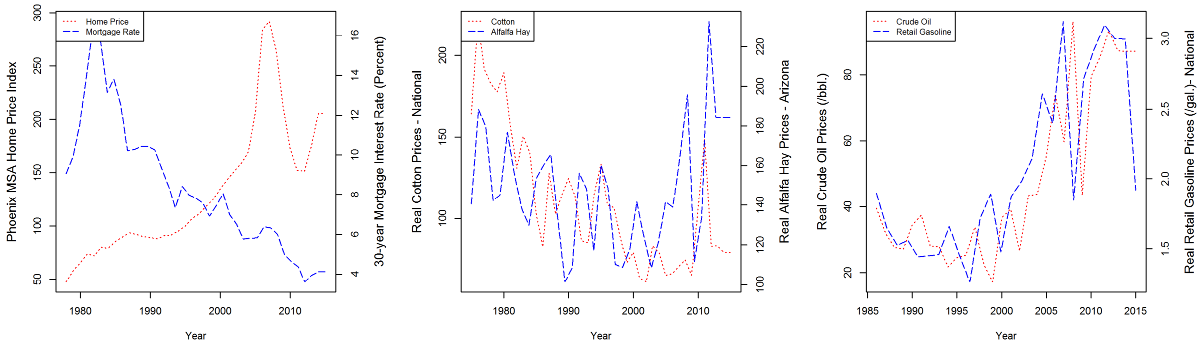

Figure 3: Comparison of Long-Term Market Indicators

An additional hypothesis using an interaction term can investigate to what extent fuel 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 both farms and urban development depends on water availability, many farms still exist in fairly central parts of the region. We hypothesize that all else equal, residential conversions will take place nearer the urban center when fuel 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.

Results and Discussion

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. 90m resolution results are shown in Figure 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 2014. Figure 4 also splits this survival probability curve by the side of town and soil quality category.

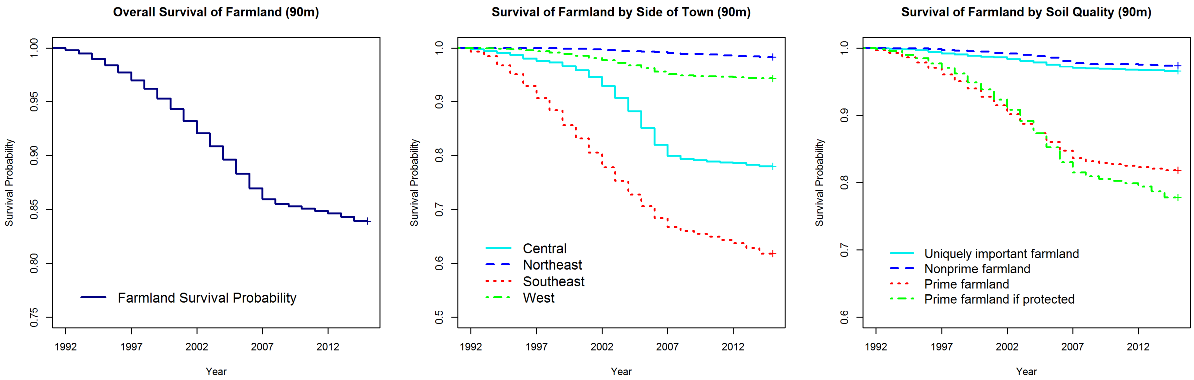

Figure 4: Survival Curves for Categorical Variables (90m resolution)

Functional form

In order to test the robustness of our choice to use the continuous-time Cox hazards model, we also conducted estimation of the same-period main effects variables using a logistic regression and a complementary log-log regression (Appendix A). While coefficient estimates vary slightly, the sign and significance test results – for all covariates across 90m and 60m resolutions – do not differ appreciably from the Cox hazards model[v]. Therefore the remainder of discussion will focus exclusively on Cox model results. OLS regressions of the same model are also run to diagnose multicollinearity; no variance inflation factors are above 3 suggesting it is unproblematic.

Cox hazards model results

A first glance at parameter estimates and their associated hazard ratios in Tables 2, 3, and 4 indicates first that, no matter the scale, chi-squared values are high and nearly all variables are statistically significant at the $p<0.001$ level (the lone exception is cotton price evaluated at 360m resolution). This is principally a function of the high number of observations in the model. For the 60m resolution models, 573,029 agricultural cells results in 12,716,317 regression observations since each cell is observed every year until it converts. 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 evaluated using a chi-squared test. We also present standardized coefficient estimates and hazard ratios to compare the relative magnitude of each covariate's impact, regardless of units.

TABLE 2: COX PROPORTIONAL HAZARDS MODEL RESULTS, 360m RESOLUTION

Covariate	Estimate	*std. error*	Standardized Estimate	Hazard Ratio	Standardized Hazard Ratio	*Wald $\chi2$*
Log Distance to CBD	-1.1942	*(0.0359)*	-0.8374	0.303	0.433	*(1109.52**)*
Side of Town						
Central (vs. west)	-0.5438	*(0.0567)*	-0.1683	0.581	0.845	*(92.12**)*
Northeast (vs. west)	-1.7577	*(0.1392)*	-0.2745	0.172	0.76	*(159.43**)*
Southeast (vs. west)	0.8092	*(0.0303)*	0.2968	2.246	1.346	*(715.2**)*
Soil Quality						
Farmland of unique importance	-1.0154	*(0.07)*	-0.3942	0.362	0.674	*(210.22**)*
Not prime farmland	-0.4353	*(0.0853)*	-0.1004	0.647	0.904	*(26.06**)*
Prime farmland if irrigated	0.3178	*(0.0292)*	0.1586	1.374	1.172	*(118.7**)*
Dist. to nearest existing hwy	0.1143	*(0.0058)*	0.7609	1.121	2.14	*(384.9**)*
Dist. to nearest planned hwy	-0.1644	*(0.0066)*	-1.117	0.848	0.327	*(626.99**)*
Phoenix MSA Home Price Index	0.0063	*(0.0004)*	0.3282	1.006	1.389	*(252.58**)*
AZ Alfalfa Hay Price	-0.005	*(0.0006)*	-0.1615	0.995	0.851	*(62.2**)*
Cotton Price (A Index)	-0.0005	*(0.0009)*	-0.01	1	0.99	*(0.24)*
Crude Oil Price	-0.0101	*(0.0009)*	-0.338	0.99	0.713	*(122.31**)*
30-yr Home Mortgage Rate	0.0078	*(0.0009)*	0.246	1.008	1.279	*(77.58**)*
Number of years since annexed	-0.0207	*(0.002)*	-0.1832	0.979	0.833	*(111.56**)*
Incorporated (vs. unincorporated)	0.7588	*(0.0436)*	0.2809	2.136	1.324	*(302.51**)*
Converting cells	6,044		Model *n*	369,655		
Total cells	19,188		AIC	145,064		

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

TABLE 3: COX PROPORTIONAL HAZARDS MODEL RESULTS, 90m RESOLUTION

Covariate	Estimate	*std. error*	Standardized Estimate	Hazard Ratio	Standardized Hazard Ratio	*Wald $\chi2$*
Log Distance to CBD	-1.1864	*(0.0156)*	-0.818	0.305	0.441	*(5779.42**)*
Side of Town						
Central (vs. west)	-0.5398	*(0.0209)*	-0.1692	0.583	0.844	*(665.81**)*
Northeast (vs. west)	-2.8261	*(0.121)*	-0.4294	0.059	0.651	*(545.47**)*
Southeast (vs. west)	0.7537	*(0.0107)*	0.2912	2.125	1.338	*(4983.12**)*
Soil Quality						
Farmland of unique importance	-0.6687	*(0.0272)*	-0.2464	0.512	0.782	*(602.75**)*
Not prime farmland	-0.5536	*(0.0441)*	-0.1055	0.575	0.9	*(157.71**)*
Prime farmland if irrigated	0.3189	*(0.0106)*	0.1582	1.376	1.171	*(909.22**)*
Dist. to nearest existing hwy	0.1277	*(0.0021)*	0.8327	1.136	2.299	*(3654.83**)*
Dist. to nearest planned hwy	-0.1839	*(0.0025)*	-1.2219	0.832	0.295	*(5351.15**)*
Phoenix MSA Home Price Index	0.0079	*(0.0001)*	0.4166	1.008	1.517	*(3690.46**)*
AZ Alfalfa Hay Price	-0.0055	*(0.0002)*	-0.179	0.995	0.836	*(671.86**)*
Cotton Price (A Index)	-0.0012	*(0.0003)*	-0.0268	0.999	0.974	*(12.87**)*
Crude Oil Price	-0.0115	*(0.0003)*	-0.3854	0.989	0.68	*(1343.37**)*
30-yr Home Mortgage Rate	-0.0035	*(0.0003)*	-0.1116	0.996	0.894	*(131.31**)*
Number of years since annexed	-0.0327	*(0.0006)*	-0.3569	0.968	0.7	*(3447.67**)*
Incorporated (vs. unincorporated)	1.7943	*(0.0135)*	0.8226	6.015	2.276	*(17658.63**)*
Converting cells	45,422		Model *n*	5,796,749		
Total cells	265,892		AIC	1,326,798		

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

TABLE 4: COX PROPORTIONAL HAZARDS MODEL RESULTS, 60m RESOLUTION

Covariate	**Estimate**	***std. error***	**Hazard Ratio**	**Standardized Estimate**	**Standardized Hazard Ratio**	***Wald $\chi2$***
Log Distance to CBD	-1.1412	*(0.0123)*	0.319	-0.7809	0.458	*(8679.02**)*
Side of Town						
Central (vs. west)	-0.5038	*(0.0157)*	0.604	-0.1571	0.855	*(1035.44**)*
Northeast (vs. west)	-3.002	*(0.1171)*	0.05	-0.4554	0.634	*(657.49**)*
Southeast (vs. west)	0.698	*(0.0079)*	2.01	0.2713	1.312	*(7787.94**)*
Soil Quality						
Farmland of unique importance	-0.522	*(0.0205)*	0.593	-0.1905	0.827	*(651.73**)*
Not prime farmland	-0.4888	*(0.0343)*	0.613	-0.088	0.916	*(202.76**)*
Prime farmland if irrigated	0.331	*(0.0079)*	1.392	0.164	1.178	*(1761.61**)*
Dist. to nearest existing hwy	0.1284	*(0.0016)*	1.137	0.8341	2.303	*(6772.13**)*
Dist. to nearest planned hwy	-0.1897	*(0.0019)*	0.827	-1.256	0.285	*(9897.84**)*
Phoenix MSA Home Price Index	0.0075	*(0.0001)*	1.008	0.3984	1.489	*(6167.69**)*
AZ Alfalfa Hay Price	-0.0057	*(0.0002)*	0.994	-0.1879	0.829	*(1365.25**)*
Cotton Price (A Index)	-0.0023	*(0.0003)*	0.998	-0.0498	0.951	*(79.26**)*
Crude Oil Price	-0.0116	*(0.0002)*	0.988	-0.3923	0.676	*(2551.18**)*
30-yr Home Mortgage Rate	-0.005	*(0.0002)*	0.995	-0.1591	0.853	*(484.39**)*
Number of years since annexed	-0.0323	*(0.0004)*	0.968	-0.3559	0.701	*(6393.07**)*
Incorporated (vs. unincorporated)	2.2474	*(0.0112)*	9.463	1.0514	2.862	*(40395.4**)*
Converting cells	82,244		Model *n*	12,716,317		
Total cells	573,029		AIC	2,515,505		

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

Main effects – spatial covariates

The effect of distance to downtown on the hazard of conversion is strongly negative at all resolutions –a cell that is one additional (log) kilometer from downtown Phoenix is 30.3% to 31.9% as likely to convert as one that is nearer. Standardized coefficient estimates ranging from -0.78 to -0.84 based on resolution are amongst the highest in absolute value of any covariate, indicating that proximity to downtown continues to be of the most important factors impacting land change over this period while outlying agricultural areas are less likely to develop. Results across all resolutions indicate that the risk of conversion is highest in the southeast valley, followed by the west, central, then northeast, which can be seen graphically in Figure 4. An element of sensitivity to resolution is apparent in the results for the northeast subregion, which shows a much lower hazard of conversion (approximately three times lower) in the 90m and 60m models when compared to the coarse resolution 360m model. Seeing this difference, subsequent interpretation of results will focus on 90m and 60m resolution models which are closer in size to individual land parcels.

The contention that urbanization is most prevalent on the best farmland is not supported (see Figure 4 and Tables 2-4). Hazard ratios of 0.512 and 0.593 on farmland of unique importance indicate that such land is a bit more than half as likely to convert than land with the third-best soil quality (the reference 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. 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, which will be explored in future work. Following the state's 1980 Groundwater Management Act, a developer must demonstrate a 100-year supply of water before beginning construction. This is often a minimally-binding constraint on agricultural land which necessarily has existing water rights, but development on previously unoccupied desert requires a more difficult and expensive process to meet this requirement (Staudenmaier, 2007). Thus land with any kind of farming is more desirable for development and due to the challenges and costs of agricultural production in the desert any land under production is on fairly good soils possibly leading to the lack of clarity between soil quality categories.

Main effects – institutional covariates

Accessibility to the freeway network was assessed in two ways: miles to the nearest freeway that had been built, representing actual accessibility and miles to the nearest planned freeway according to the 1985 regional plan, representing the possibility of freeway-induced development. The impact of planned versus existing freeways contrasts significantly: proximity to an existing freeway is among the strongest drivers of land conversion – being an additional mile nearer an existing freeway causes units of land to be 1.136-1.137 times as likely to convert into housing. However, distance to the nearest planned freeway is in fact the strongest overall *negative* predictor of land development, with a hazard ratio of 0.827-0.832 depending on resolution– being far from planned freeways predicts development more than anything else. This does not support the notion of induced development. Instead, it largely reflects that freeway planning is a long-term process: developers and homebuyers are likely aware that accessibility benefits promised in a very long-range planning document may not come to fruition for a long time if at all. Furthermore, inductive effects of land development may be better reflected in land purchase decisions or land prices – in the case of the proposed Loop 303 freeway in the west portion of the region, speculators did begin purchasing land long before freeway construction. Our results, in contrast, measure when a new home was first occupied which is the culmination of the development process and a point at which realized accessibility is more important than proposed accessibility. Many areas near proposed freeways, particularly early in the study period, were in extremely remote areas at the time and as such would be expected to be less likely to convert.

The Phoenix area has a long history of competitive land annexation between municipalities (Heim, 2012). Results show that whether an agricultural parcel is within municipal boundaries is by far the strongest contributor to its hazard of conversion with hazard ratios between 6 and 9.5 and a standardized coefficient estimate comparable in magnitude to freeway and downtown proximity, the other very strong predictors of land conversion. However, the number of years elapsed since land was first included within municipal borders has a negative effect on the hazard of land conversion: each additional year elapsed since annexation reduced the hazard of conversion slightly (with a hazard ratio of 0.968). 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 several times smaller based on standardized estimates, it does indicate 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

Main effects – market covariates

Oil prices, gasoline prices, and mortgage rates have been indexed to their 2010 values so that they are directly comparable to home and commodity price indices, which are provided in this manner. As expected, the metropolitan-level home price index has a positive and significant impact on the hazard of conversion – a one percentage point increase in home-price index increases the hazard of conversion by 0.7% to 0.8%. Conversely, a one percentage point increase in the regional price of alfalfa hay decreases conversion hazard by 0.6% to 0.7%. Thus home and hay prices have opposite impacts on land conversion, but of similar magnitude. The relationship between cotton prices, which is traded on a global market, and conversion hazard operates in the same direction as alfalfa hay but is far weaker; a one percentage point increase decreases conversion hazard by 0.1% to 0.2%.

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 spending. Since oil and gasoline prices are highly collinear, they must be estimated separately – models using oil prices have consistently higher AIC scores indicating better model fit and are thus relied upon for analyzing main effects (see Table 6 for interaction effects which include gasoline prices). Overall, oil price has a strong, negative coefficient: a one percentage point increase decreases the hazard of conversion by 1.1% to 1.2% -- 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.

We hypothesized that lower mortgage rates would increase home buying and thus increase conversion hazard. Evidence supporting this hypothesis is found at 90m and 60m resolutions, where hazard ratios indicate a one percentage point increase in the (indexed) mortgage rate results in a 0.4% to 0.5% decrease in conversion hazard. However at 360m resolution, the hazard ratio is positive (1.008), indicating that higher mortgage rates actually increase the hazard of land conversion. While this difference was unexpected, it makes sense since regression observations at 360m resolution represent about 48 homes each, while the lower resolution models are more reflective of the impact on individual residential completions. Land observed at 360m includes additional land area that is unrelated to individual residential completions such as roads and easements purchased by a developer that cannot be developed into housing, and also neighboring farmland that is not part of any development purchase. Regarding the former, a developer holding such land may be more motivated to develop and sell when interest rates are high to reduce his holding costs. The latter case adds statistical noise.

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.

TABLE 5: COX MODEL HAZARD RATIOS AND ESTIMATES FOR LAGGED PRICE EFFECTS*

		90m	*60m*	*90m*	*60m*	*90m*	*60m*
	Result	**Current Year**		**Prior Year**		**Two Years Prior**	
Phoenix MSA Home Price Index	Hazard Ratio	1.008	1.008	1.005	1.005	1.003	1.003
	Estimate$^+$	*0.41661*	*0.3984*	*0.28508*	*0.28016*	*0.14979*	*0.15152*
AZ Alfalfa Hay Price	Hazard Ratio	0.995	0.994	0.993	0.993	0.993	0.992
	Estimate$^+$	*-0.17901*	*-0.1879*	*-0.20624*	*-0.23009*	*-0.2131*	*-0.24357*
Crude Oil Price	Hazard Ratio	0.989	0.988	0.984	0.983	0.98	0.979
	Estimate$^+$	*-0.38538*	*-0.3923*	*-0.51764*	*-0.54653*	*-0.60949*	*-0.64772*
30-Year Home Mortgage Rate	Hazard Ratio	0.996	0.995	0.991	0.989	0.988	0.986
	Estimate$^+$	*-0.11155*	*-0.1591*	*-0.29796*	*-0.36674*	*-0.4207*	*-0.49078*
AIC - Whole Model *(thousands)*		1,326,798	2,515,505	1,328,421	2,517,861	1,327,628	2,515,458

**all results significant at $p<0.001$, $^+$ indicates a standardized value*

The Cox regressions for 90m and 60m were re-estimated replacing current year prices with previous year values and values from two years prior; hazard ratios and standardized estimates are shown in Table 5. AIC scores indicate that model fits were strongest using same-year indices or indices from two years prior, but weaker using indices from the previous year. The positive effect of indexed home prices on conversion hazard 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 speculative 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 (Brown, 2015). This explanation seems plausible given that our outcome measure of land development only considers developments that were actually built – not the ones that failed to materialize. As expected the lagged impact of mortgage rates show the opposite: present-day land conversion is negatively impacted by higher mortgage rates, but it is much more negatively impacted by high mortgage rates from one or two years prior. In other words, land conversion today is most impacted by mortgage rates from two years ago and current home prices. New homes hit the market when prices are higher than they'd been in prior years, and when financing for homebuyers has become less expensive. These results are consistent with the trend of increasing home prices and decreasing mortgage interest rates over the 23-year study period (Figure 4).

The negative effect of alfalfa hay prices on land conversion does not change appreciably when lagged prices are substituted: expectations are no more or less important than present-day values. Oil prices behave similarly to mortgage interest rates in that their negative impact on conversion hazard is strongest two years prior to development – high crude oil prices two years ago decrease land conversion hazard today. Two-year lagged oil price has more impact on the land conversion process than any other economic indicator included in the model, as indicated by the standardized coefficient estimate of -0.65 at 60m resolution. Two-year lagged mortgage interest rates, with a standardized estimate of -0.49 are the second-highest, while same-year home prices are the third most impactful at roughly 0.40.

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

TABLE 6: HAZARD RATIOS FOR INTERACTION EFFECTS

Crude Oil Price and Dist. CBD			Retail Gasoline Price and Dist. CBD			Home Prices and Years Since Annexed		
Oil Price$^+$	Dist. CBD Hazard Ratio	Dist. CBD Hazard Ratio	Gas Price$^+$	Dist. CBD Hazard Ratio	Dist. CBD Hazard Ratio	Home Prices$^+$	Yrs. Since Annexed Hazard Ratio	Yrs. Since Annexed Hazard Ratio
	*90m***	*60m***		*90m***	*60m***		*90m***	*60m***
22 (min)	0.328	0.348	47 (min)	0.326	0.345	121 (min.)	0.983	0.984
35	0.322	0.340	57	0.319	0.336	170	0.975	0.976
50	0.315	0.331	70	0.310	0.324	220	0.967	0.968
90	0.297	0.307	95	0.294	0.303	270	0.960	0.959
122 (max)	0.283	0.290	117 (max)	0.280	0.286	322 (max.)	0.952	0.951

*$p<0.05$, **$p<0.001$, $^+$ *indicates an indexed value*

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 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 and significant in both 90m and 60m models indicating reinforcing effects. Table 6 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 $\beta_{1,2}$. When oil prices were at their lowest, an additional kilometer away from the region's core decreases conversion hazard by 65% to 67% depending on resolution. When oil prices were at their highest, an additional kilometer decreases conversion hazard by 71% to 72%. This supports the hypothesis about transportation cost substitution: when fuel prices are high, outlying areas requiring a long commute appear less attractive so land near the urban core which tends to be more expensive is more likely to be developed – even in a region that relies more heavily on subcenters than a single downtown. While this study excludes new housing that was not the result of farmland conversion it improves on previous work by examining within-city development decisions over a time horizon which saw drastic (more than fivefold) swings in oil price.

Finally, we 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.

Conclusions

This study investigates the conversion of agricultural land in the Phoenix metropolitan area from 1992 to 2014 using survival analysis to make a spatially explicit empirical connection between land-use change, prices, policy, and place While previous survival analyses of land change are more limited in extent, we analyze an entire metropolitan region which is emblematic of fast-growth conditions in urban regimes worldwide. Phoenix's environmental sensitivity, low cost of living, and undersized downtown are consistent with global urban expansion trends, which are increasingly taking a dispersed, suburban form.

Perhaps surprisingly in a region known for its dispersed nature, place remains very important: proximity to the downtown core is among the strongest predictors of agricultural conversion, suggesting this is a heavily embedded characteristic of urban development. The effect of centrality is comparable to the positive impact of proximity to existing freeways. In contrast, proximity to a planned freeway actually reflects a strong decrease in conversion risk. This is inconsistent with the hypothesis that freeway planning induces development, and emphasizes that region-wide, planned freeways may be very speculative or in outlying areas that will not be at risk of conversion until the distant future. A caveat may be that this study measures land conversion at the point of new home occupancy, while speculative land purchases, sale-leasebacks, distortions in prices, and other developer activity not reflected in this measure may indeed result from long-range freeway planning, yet these activities do not necessarily result in actual land-use change. In addition, development trajectories differ across subregions, while farmland with the best soil is not necessarily at the highest risk of development.

While most prior survival analyses of land change have focused on the impact of growth management policy, in the absence of strong preservation efforts, we find that 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.

Instead, the focus in this study has been on the role of prices across an entire region and gauging the magnitude of the role of varying market conditions on land conversion and urban morphological change. Regional peculiarities, differences in data structure, spatial resolution, and the measure of development timing may all impact results, thus it is difficult to definitively rank the relative impact of price, policy, and place-based drivers of land development, especially beyond the study area. In this study, intraurban location and municipal incorporation appear to have the strongest impact on land conversion, but they are followed closely by market indicators: in particular, oil prices, mortgage interest rates, regional home prices, and agricultural commodities indices, roughly in decreasing order of magnitude. In other words, intraurban location and annexation matter, but global market conditions are not far behind. The strong impact of current home prices on conversion hazard contrasts sharply with the strong lagged effects of mortgage interest rates. This is an important finding about land speculation in the long term and suggests that Greenfield development is timed such that new product hits the market when it is high priced. Given that the timeline for developing housing is generally a couple of years from commitment to occupancy, developers appear to be responding mostly to interest rates rather than regional home prices. This reflects the financialized nature of housing development, consistent with the post-financial crisis perspective that global market forces have a disproportionate hand in urban development with the lending standards of the secondary mortgage market trumping local conditions (see, e.g., Martin, 2010). The strong impact of oil prices, especially when lagged measures are considered, clearly demonstrates the reach of global economic conditions on land change decisions. The advantage of our approach is that its 23-year time horizon suggests this feature is more lasting than a single boom or bust; rather, financialization of development decisions appears to be a more deeply embedded characteristic of urban growth. As such, future research on urban land-use change especially in other large metropolitan regions should strive to include market indicators alongside policy-based and place-based drivers of change.

Finally, the impact of oil prices on land change also merits special consideration: agricultural land closer to the region's center is more likely to convert in times of high oil prices, suggesting that compact growth near downtown might be seen more favorably in times of high transportation cost. This is encouraging for promoters of smart growth and planners seeking to internalize the negative externalities associated with fringe growth such as freeway congestion, excessive fuel use, and pollution. While the long-term history of cities has emphasized how continually lower transportation costs give urban areas a larger and less dense footprint, this study provides some evidence that increases in transportation cost could result in a more compact urban form, especially if promoted by appropriate policy initiatives such as location-efficient mortgages. Again, that this sensitivity is observed in a low-cost, high-growth dispersed metro region is additionally meaningful, yet future research should strive to evaluate this across multiple regions. These results suggest that further study could uncover new insights about how recent global changes impact location choices and urban form.

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[i] The Arizona Agricultural Property manual defines "qualified" agricultural purposes. The main criteria is based on use rather than ownership: the land must have been in economically feasible production for three of the past five years, per Arizona Revised Statute 42-13101. The manual stipulates an income capitalization approach to value with the stipulation that the valuation is "without any allowance for urban or market influences." This is the impetus for the common sale-leaseback arrangement.

[ii] Grid cells of land were considered to be agricultural if at least 5% of the land area identified in 1992 as one of the NLCD agricultural categories: pasture/hay (81), row crops (82), small grains (83), and fallow land (84). In the case of 60m grid cells, only one NLCD pixel need be agricultural (25%) while in the case of 360m grid cells, at least 7 pixels (out of 144) must be in an agricultural category for the cell to be considered farmland in this analysis.

[iii] A small area of Maricopa County is located in the Tonto National Forest for which soil survey data is not available. This area is excluded since it is not relevant to residential development.

[iv] While using a sub-regional housing price index may better reflect a landowner's sale decision, it may also cause endogeneity with spatially disaggregated determinants of land conversion included elsewhere in the model. This approach keeps spatial and temporal elements distinct, allowing the study to observe the impact of fluctuating market trends alongside spatially disaggregated determinants of value.

APPENDIX A

APPENDIX A1: LOGISTIC REGESSION RESULTS, 90m RESOLUTION

Covariate	**Estimate**	***std. error***	**Odds Ratio**	***Wald χ2***
Log Distance to CBD	-1.1911	*(0.0159)*	0.304	*(5618.73**)*
Side of Town				
Central (vs. west)	0.0982	*(0.0332)*	0.578	*(8.76*)*
Northeast (vs. west)	-2.14	*(0.0906)*	0.062	*(557.42**)*
Southeast (vs. west)	1.3947	*(0.0313)*	2.112	*(1982.02**)*
Soil Quality				
Farmland of unique importance	-0.6801	*(0.0274)*	0.507	*(618**)*
Not prime farmland	0.292	*(0.0107)*	0.577	*(742.74**)*
Prime farmland if irrigated	-0.5499	*(0.0443)*	1.339	*(154.01**)*
Dist. to nearest existing hwy	0.1221	*(0.0022)*	1.13	*(3211.6**)*
Dist. to nearest planned hwy	-0.179	*(0.0026)*	0.836	*(4846.93**)*
Phoenix MSA Home Price Index	0.0082	*(0.0001)*	1.008	*(3203.23**)*
AZ Alfalfa Hay Price	-0.0062	*(0.0002)*	0.994	*(799.32**)*
Cotton Price (A Index)	-0.0011	*(0.0003)*	0.999	*(9.49*)*
Crude Oil Price	-0.0128	*(0.0003)*	0.987	*(1352.37**)*
30-yr Home Mortgage Rate	-0.0021	*(0.0005)*	0.998	*(15.52**)*
Number of years since annexed	-0.0318	*(0.0006)*	0.969	*(3168.86**)*
Incorporated (vs. unincorporated)	1.7382	*(0.0137)*	5.687	*(16175.27**)*
Year	0.025	*(0.0031)*	1.025	*(66.58**)*
Converting cells	45,422		Model n	5,796,749
Total cells	265,892		AIC	449,831

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

APPENDIX A2: COMPLEMENTARY LOG-LOG RESULTS, 90m RES.

Covariate	**Estimate**	***std. error***	**-**	***Wald χ2***
Log Distance to CBD	-1.1764	*(0.0157)*		*(5606.82**)*
Side of Town				
Central (vs. west)	0.1054	*(0.0331)*		*(10.13*)*
Northeast (vs. west)	-2.1321	*(0.0906)*		*(553.72**)*
Southeast (vs. west)	1.3811	*(0.0313)*		*(1948.29**)*
Soil Quality				
Farmland of unique importance	-0.6763	*(0.0272)*		*(618.21**)*
Not prime farmland	-0.5469	*(0.0441)*		*(153.93**)*
Prime farmland if irrigated	0.2876	*(0.0106)*		*(741.96**)*
Dist. to nearest existing hwy	0.1203	*(0.0021)*		*(3228.2**)*
Dist. to nearest planned hwy	-0.1763	*(0.0025)*		*(4856.88**)*
Phoenix MSA Home Price Index	0.0081	*(0.0001)*		*(3204.63**)*
AZ Alfalfa Hay Price	-0.0062	*(0.0002)*		*(800.74**)*
Cotton Price (A Index)	-0.0011	*(0.0003)*		*(9.46*)*
Crude Oil Price	-0.0126	*(0.0003)*		*(1347.97**)*
30-yr Home Mortgage Rate	-0.0021	*(0.0005)*		*(16.35**)*
Number of years since annexed	-0.0313	*(0.0006)*		*(3169.1**)*
Incorporated (vs. unincorporated)	1.7188	*(0.0135)*		*(16189.09**)*
Year	0.0243	*(0.003)*		*(64.18**)*
Converting cells	45,422		Model n	5,796,749
Total cells	265,892		AIC	449,954

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

APPENDIX A3: LOGISTIC REGESSION RESULTS, 60m RESOLUTION

Covariate	**Estimate**	***std. error***	**Odds Ratio**	***Wald χ2***
Log Distance to CBD	-1.1464	*(0.0125)*	0.318	*(8478.15**)*
Side of Town				
Central (vs. west)	0.1862	*(0.0311)*	0.6	*(35.86**)*
Northeast (vs. west)	-2.2757	*(0.088)*	0.051	*(668.8**)*
Southeast (vs. west)	1.3916	*(0.03)*	2.001	*(2149.4**)*
Soil Quality				
Farmland of unique importance	-0.5343	*(0.0205)*	0.586	*(676.32**)*
Not prime farmland	-0.486	*(0.0345)*	0.615	*(198.59**)*
Prime farmland if irrigated	0.306	*(0.008)*	1.358	*(1471.73**)*
Dist. to nearest existing hwy	0.1231	*(0.0016)*	1.131	*(6008.39**)*
Dist. to nearest planned hwy	-0.1851	*(0.002)*	0.831	*(9037.92**)*
Phoenix MSA Home Price Index	0.0078	*(0.0001)*	1.008	*(5429.65**)*
AZ Alfalfa Hay Price	-0.0064	*(0.0002)*	0.994	*(1563.44**)*
Cotton Price (A Index)	-0.0022	*(0.0003)*	0.998	*(69.83**)*
Crude Oil Price	-0.0127	*(0.0003)*	0.987	*(2442.69**)*
30-yr Home Mortgage Rate	-0.004	*(0.0004)*	0.996	*(106.19**)*
Number of years since annexed	-0.0315	*(0.0004)*	0.969	*(5955.25**)*
Incorporated (vs. unincorporated)	2.191	*(0.0113)*	8.944	*(37820.36**)*
Year	0.0207	*(0.0023)*	1.021	*(81.24**)*
Converting cells	82,224		Model n	12,716,317
Total cells	573,029		AIC	828,959

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

APPENDIX A4: COMPLEMENTARY LOG-LOG RESULTS, 60m RES.

Covariate	**Estimate**	***std. error***	**-**	***Wald χ2***
Log Distance to CBD	-1.1326	*(0.0123)*		*(8449.53**)*
Side of Town				
Central (vs. west)	0.1924	*(0.031)*		*(38.38**)*
Northeast (vs. west)	-2.2684	*(0.088)*		*(665.1**)*
Southeast (vs. west)	1.3797	*(0.03)*		*(2116.59**)*
Soil Quality				
Farmland of unique importance	-0.5313	*(0.0204)*		*(676.66**)*
Not prime farmland	-0.4843	*(0.0343)*		*(199.12**)*
Prime farmland if irrigated	0.3016	*(0.0079)*		*(1468.13**)*
Dist. to nearest existing hwy	0.1214	*(0.0016)*		*(6034.85**)*
Dist. to nearest planned hwy	-0.1824	*(0.0019)*		*(9047.51**)*
Phoenix MSA Home Price Index	0.0077	*(0.0001)*		*(5431.05**)*
AZ Alfalfa Hay Price	-0.0063	*(0.0002)*		*(1570.81**)*
Cotton Price (A Index)	-0.0022	*(0.0003)*		*(69.96**)*
Crude Oil Price	-0.0126	*(0.0003)*		*(2435.98**)*
30-yr Home Mortgage Rate	-0.004	*(0.0004)*		*(108.73**)*
Number of years since annexed	-0.031	*(0.0004)*		*(5942.93**)*
Incorporated (vs. unincorporated)	2.1737	*(0.0112)*		*(37747.19**)*
Year	0.0201	*(0.0023)*		*(78.22**)*
Converting cells	82,224		Model n	12,716,317
Total cells	573,029		AIC	829,131

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

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