"TOO SMALL TO FARM, TOO BIG TO MOW": THE IMPACT OF LARGE-LOT ZONING ON THE EXURBAN LANDSCAPE

by

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ABSTRACT OF THE THESIS

"Too small to Farm, Too Big to Mow"; The Impact of Large-Lot Zoning on the Exurban Landscape

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Farmers often oppose large-lot zoning because they believe it will reduce the value of their land. Non-farm homeowners frequently support such zoning because they believe that minimum lot size restrictions will postpone development and preserve "rural character." Planners, meanwhile, worry that if development does occur, minimum lot size restrictions will create an environmentally harmful landscape consisting of houses on large lots that are widely separated by expanses of manicured lawn. This latter outcome is one definition of urban sprawl. It is a potential unintended consequence of a local land use policy that is otherwise quite popular.

Because of the controversy that surrounds local zoning policies, all of these hypothesized effects of large-lot zoning are worth exploring empirically. Agricultural and resource economists have written on this subject, but they tend to lack zoning and landscape data that are sufficiently detailed to explore the policy questions of interest.

Using a detailed GIS dataset of 83 municipalities in the New Jersey Highlands, the current thesis estimates the effect of actual minimum lot size in each zone (half-acre,

one acre, etc.) on the number of acres converted from forest, grassland, or farmland to residential landscapes (structures and adjoining lawns) between the years 1995 and 2002. While this thesis does not formally adjust for selection bias in the zoning treatment, preliminary analysis of covariate balance suggests that a simple regression approach might be adequate for causal analysis, at least for this dataset. The results of the simple regression analysis of the effects of minimum lot size alongside other growth drivers suggest that minimum lot size imposition as a policy tool works as intended.

Acknowledgement

This thesis is dedicated to my father, Jeffry Lubeck, whose constant motivation throughout my life has pushed me to further my educational goals. It is also dedicated to my mother, Margaret Lubeck, for the immense support that she provided during this time.

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Introduction

Economists Van Butsic, Lewis, and Ludwig (2011) provide a useful and fairly recent summary of the relationship between local zoning and urban sprawl, which will be defined for present purposes as "excessive land consumption." They begin with a discussion of why urban sprawl is a policy problem:

> Urban sprawl is criticized largely on the grounds that development consumes an excessive amount of land that would otherwise have provided market and nonmarket benefits associated with open space. A corollary of excess sprawl is the loss of farmland, since exurban growth often occurs in areas that are primarily agricultural. Local zoning ordinances remain probably the most widespread land use control influencing sprawl (Van Butsic, 2011, p.3).

The authors' use of the word "probably" in this passage is interesting, because they themselves do not appear to be convinced that zoning's influence on landscape change has been conclusively proven. Van Butsic, Lewis and Ludwig quote Fischel (2000), who argues that local government zoning laws, particularly those that impose large minimum lot sizes, contribute to low density development patterns. At the same time, Van Butsic, Lewis and Ludwig assert that there is little empirical data to support Fischel's claim, citing McConnell, Walls, and Kopits (2006), among others.

At least in the economics literature, a major reason why such evidence is lacking is that economists typically do not study landscape change as an outcome. The vast majority of economic studies look at the effect of zoning on land or housing prices, not on landscape change (Pollakowski and Wachter, 1990; Ihlanfeldt, 2007; Deaton and Vyn, 2010). While several papers estimate zoning's effect on the development decisions of rural landowners (Van Butsic, et al., 2011, Carrion-Flores and Irwin, 2004), or on development "leapfrogging" at the metropolitan scale (Vyn, 2012), virtually no economists analyze the effects of zoning on a measure of land cover change as the dependent variable.

Van Butsic et al. (2011) provide another important reason why findings on the relationship between zoning and suburban land development are inconclusive. They point out that few analysts of the landowner development decision have adjusted for likely selection bias in the zoning treatment (see also McMillen, 1989, Pogodzinski and Sass, 1991). When Van Butsic et al. (2011) conducted the necessary adjustments, the previously-observed negative "causal" relationship between large lot zoning and the decision to subdivide a rural parcel disappeared. One might expect the same outcome for studies of land cover change as a function of zoning, but even fewer such studies exist in the literature.

The research in this thesis will attempt to measure the cause and effect relationship between lot-size minima and residential development, expressed in terms of land cover change. The policy setting consists of eighty-three municipalities in northwestern New Jersey, referred to as the New Jersey Highlands. The counties included in this thesis are Bergen, Hunterdon, Morris, Passaic, Somerset, Sussex, and Warren. These specific counties are characterized as having a large number of commuters who travel to New York City for work, therefore the area has a higher probability of becoming urbanized due to its proximity to the city.

Literature Review

Many studies have hypothesized that large lot zoning will create larger lots, lower density, or urban sprawl. McConnell et al. (2012) used a hypothetical urban fringe community to model the effects of large lot zoning on density of new development and spatial configuration over time. McConnell et al.'s urban fringe community is similar to this thesis's study area; it is defined as "an ex-urban area outside of any major U.S. city where farmland is under pressure from development" (McConnell et al., 2012)

McConnell et al. (2012) found that imposing a 2-acre minimum lot size had little effect on the spatial patterns of development. At a 5-acre minimum lot size, however, they found that development is pushed toward un-zoned areas, leaving the 5-acre lots undeveloped, thereby inducing sprawl.

Fischel (2000) also argues that minimum lot size zoning requirements can magnify sprawling patterns by forcing consumption of larger lot sizes than the market would impose in the absence of zoning (Fischel, 2000). A problem with both of these papers, however, is that one is entirely theoretical and the other is based on simulations, instead of real-world data.

Other studies have examined the relationship between zoning and the number of lots developed within particular subdivisions. A study conducted by Lichtenberg and Hardie (2007) focused on the relationship between minimum lot size zoning and urban sprawl in Baltimore-Washington suburbs. Their study found that there was a positive relationship between minimum lot size zoning and average developed lot size and a negative relationship between minimum lot size and the number of lots. They concluded that minimum lot size zoning has a significant impact on sprawl (Lichtenberg and Hardie, 2007).

Another research paper conducted by authors previously mentioned, McConnell, Walls, and Kopits (2006), examined the question of whether or not zoning regulations create low-density, land-intensive development. These authors also studied the decisions of Maryland developers on density at the subdivision level. Their research found that high minimum lot sizes were correlated with reduced development density (McConnell, Walls, Kopits, 2006). Although these results suggest that if zoning restrictions were relaxed more development would have occurred, this correlation does not necessarily mean causation. Variables such as the value and cost of the land, the steepness of the slope on the land, and accessibility to highways were factors that also influenced the density along with the imposition of zoning restrictions (McConnell, Walls, Kopits, 2006).

Alternative studies estimate the effect of zoning using large undeveloped parcels as their unit of analysis. Van Butsic (2011) conducted a parcel level econometric analysis to determine landowners' decisions to develop or to not develop their lands. Their research suggested that zoning does *not* modify land development and that "zoning may simply follow the market" because areas of high demand are more likely to be zoned to allow development than areas that have low demand (Van Butsic, 2011). These authors found that they could not reject the null hypothesis that exclusionary agricultural zoning had no effect on landowner development decision, controlling for selection effects. They also discovered that the Wisconsin farmland preservation program has a weak effect on the development decisions of landowners (Van Butsic, 2011).

A similar study by Carrión-Flores and Irwin (2001) used parcel level data to analyze the effects of large lot zoning based on the development decisions of landowners in Ohio, but did not adjust for endogenous zoning. This study found that the mere existence of zoning policies such as lot size minima had a significant and positive marginal effect on residential land conversion, and that "several factors such as preferences for low-density areas, limited agglomeration economies surrounding the central city, and heterogeneity among local jurisdictions are found to be important determinants of residential land conversion" (Carrión-Flores and Irwin, 2001).

Another study of importance is one by Gottlieb et al. (2012) which researches whether minimum lot size restrictions and permanent preservation of open space affected the number of building permits issued across the 83 municipalities in the New Jersey Highlands. In other words, the dependent variable in this study was not the subdivision decisions of farmer-landowners, but rather the number of single family lots ultimately created by those decisions. This study found no evidence of a hypothesized quadratic relationship between average minimum lot size and the number of building permits. Controlling for zoned capacity, however, the effect of large minimum lot size measured at the municipal scale on the number of building permits was negative (Gottlieb, et al., 2012). This study is of interest because it cover the same geographical region as the present work.

Studies outside of the economics literature that focus on the relationship between zoning and land or tree canopy cover show different findings regarding sprawl. Although tree canopy cover is not identical to this study's land change measure, an interesting paper by York and Munroe (2010) evaluated the impact of regional level land use policies on urban sprawl in rural areas by observing the process of "urban encroachment into proximate rural areas" (Munroe 2010, 472). Their model discovered a very weak positive relationship between zoning and the conversion of land from agriculture to urban area. They also discovered that when it comes to the protection of farmland, county level zoning is weakly effective (Munroe, 2010). Overall, however, they found that they cannot confirm nor deny that policies such as minimum lot sizing have an effect on sprawl.

Studies that explore rural to suburban landscape change as a result of zoning policies are of great importance to this thesis. Munroe, Croissant, and York (2005) explored the relationship between landscape fragmentation and variables that might be expected to drive the development decision for individual parcels. Their study area, Bloomington, Indiana, is relevant to the study area in this thesis in that they both exhibited urban and suburban development sprawling out into areas that were formerly forest or agricultural cover (Munroe, 2005). Bloomington, Indiana differs from the New Jersey Highlands in that slope is not an important variable, whereas it is in this thesis. The outcome of Munroe et al's research is that "zoning policies have a greater impact on landscape and forest fragmentation in some areas of the county than other areas, i.e. in those areas where both the cost of development due to topography is lowest and development pressures (in terms of city access) are highest" (Munroe, 2005). This result highlights the importance to development of covariates like topography and distance to the urban core.

Another study that investigated landscape change in New Jersey due to development was performed by Hasse and Lathrop (2003). They identified five land resource indicators to measure where the least efficient and most damaging forms of urban sprawl are taking place, at the municipality level. These authors found that:

> The largest single type of landscape change that occurred to development growth in New Jersey over the last decade was the urbanization of forested lands. A total of 27,158 hectares of forested land were converted to urban land uses during the nine-year period of analysis (Hasse and Lathrop, 2003).

These findings appear to contradict a hypothesis presented in this thesis, that farms will urbanize more quickly than forests due to lower development costs. Hasse and Lathrop (2003) is relevant to this thesis in that it analyzes the same study area, and stresses that development is inefficiently using valuable open space resources.

Finally, a study from Michigan essentially examined the same cause and effect relationship as this thesis. This study, conducted as a masters' thesis by Brian Foley of Michigan State University, used multiple regression to quantify the relationship between the imposition of minimum lot sizes and acres developed between 1990 and 2000 (Foley, 2004). All of the variables in the Foley study were measured at the municipal scale, which means that minimum lot size had to be specified as a weighted average, with the acreage for each zone serving as the weight. Foley's study found that development is a quadratic function of minimum lot sizes: first landscape development is seen to decline with minimum lot size, but after 5.15 acres it is seen to increase with minimum lot size. Thus the study found that the relationship is U-shaped (Foley, 2004).

The purpose of this thesis is to build upon the existing literature and ascertain the relationship between minimum lot sizes and land development. Unlike studies that merely theorize that large lot zoning will create larger lots or fewer homes, this thesis presents empirical evidence. Some studies look at the relationship between zoning and the number of lots developed within particular subdivisions. The present study examines land conversion over large portions of the community. It looks not only at the effects of zoning on development density, but also on overall land footprint of development – the outcome that presumably matters most to policy makers.

This thesis also differs from studies that estimate the effect of zoning using large undeveloped parcels as the unit of analysis. In contrast to those studies, this thesis looks at the conversion of undeveloped land to suburban cover, which is of significant concern to planners. Unlike Van Butsic, et al. (2011), the present dataset permits an examination of multiple municipalities and a wider range of lot size minima. A notable difference between this thesis and both Van Butsic (2011) and Carrion-Flores (2001) is that the minimum lot size variable is continuous (programmed as multinomial) whereas theirs is binary.

Among economists, the present topic has only been examined directly by one other study, a masters' thesis conducted by Brian Foley. Foley's study was most similar to this paper in that both attempt to empirically answer the same question. However, Foley's work differed in that his unit of analysis is the municipality and my unit of analysis is the zone. This paper does not need to rely on zoning or development data that is averaged over the municipality, because the data captures both of these phenomena at the level of each residential zone within each of the 83 municipalities. It will be interesting to see if the more spatially-detailed results confirm those of Foley, or if that earlier work suffered from possible aggregation bias.

Theoretical Framework

The theoretical framework for this thesis is based on two unpublished working papers by Gottlieb (2013; 2016). Gottlieb's papers use theory and the existing literature to develop signed expectations for the relationship between minimum lot size and the magnitude of residential landscape development across municipalities (2013) and zones (2016). The earlier of the two papers presents its theoretical argument by means of graphical simulations. In contrast, Gottlieb (2016) formally specifies a set of structural and reduced form equations with their partial derivatives.

The essence of Gottlieb's argument is as follows:

(1) Owners of rural parcels decide when to subdivide by solving Capozza and Helsley's (1989; 1990) optimal timing maximization problem. That is, a large rural parcel will develop as soon as the present value of future returns from the land in its developed use exceeds the present value of future returns from continued agriculture, plus debt service payments on the cost of conversion. In Capozza and Helsley's notation, development occurs at time t*, when the following condition is first met:

$$R(t^{*}, z) = A + rC$$

The left side of this equation signifies "rent in urban use." *A* and *rC* are, respectively, agricultural returns and the amortized cost of conversion.

(2) Capozza and Helsley use the variable *z* in the urban rent function to denote distance from the urban core. This is the most powerful driver of urban rents in a study area such as the one represented in this thesis: it will feature heavily as a control in the empirical models of landscape development. It is not, however, the

only determinant of expected urban land rents. Zoning restrictions, for example, are generally thought to reduce profits to developers. If that is the case, then the existence of such restrictions should delay the conversion of rural land and reduce the number of subdivided lots ultimately brought to market. Profits aside, within a regional housing market the demand for homes on larger lots can be expected to decline -- at least at some level of MLS -- for reasons of affordability. Gottlieb et al. (2012) found a continuous decline in building permits across 83 New Jersey municipalities, as municipal average lot size grew.

(3) The fact that the current dependent variable of this thesis is based on landscape change rather than on building permits adds some complexity to the analysis. First, total land area developed could increase with higher MLS even as the number of subdivided lots declines. In an analogy to the well-known price-revenue problem, the sufficient condition for this outcome is simply that the mathematical function relating decline in the number of homes to an increase in MLS is inelastic. (There must also be a reasonably tight relationship between actual lot size and the regulatory minimum.) Second, the amount of land cover change per developed lot is likely to have a ceiling: Owners of five-acre estates do not generally mow and landscape their property all the way out to the boundary line. Acres of newly created "suburban landscape" are all that were able to be measured in the present dataset.

(4) Because very large lots are sure to be unaffordable to all but a few homebuyers, the number of units sold must eventually decline. At these very high levels of MLS, measures of residential land cover per housing unit also become fixed.

This means that total land cover must eventually decline with increasing MLS, regardless of whether the decline in building permits is elastic or inelastic with respect to this increase in MLS.

(5) At lower levels of MLS, it is assumed that each lot is landscaped in its entirety. It follows that total observed land development over this range of MLS *could* increase -- if the decline in building permits is inelastic with respect to the increase in MLS. Because there is no direct data on building permits by zone, the underlying elasticity/inelasticity can only be inferred indirectly.

(6) For all of the reasons stated here, it can be hypothesized that the relationship between residential landscape change as a function of MLS in a sample of zones is either: (a) monotonically declining, or (b) concave and single-peaked. These are the slopes/shapes that will be looked for in the empirical work to follow.

ECONOMETRIC ISSUES AND DESCRIPTION OF THE DATA

Defining the variables

The theory presented in the previous section justifies a regression model with the following structure. After eliminating all territory that was already developed in 1995, define a set of variables for each zoning class z within municipality m:

A_{zm} = number of acres in z,m that converted to residential cover between 1995 and 2002

$AREA_{zm}$ = size of zone z,m in acres.

MLS_{zm} = lot size minimum in 1995 according to local ordinance

COV_{zm} = rural land cover in 1995 (%farm, forest, etc.)

Define the following variable for each municipality m:

X_m = vector of municipal-level characteristics hypothesized to affect residential development between 1995 and 2002.

The regression model, using data for each zoning class z in each municipality m, will take the form:

$$(1)\ A_{zm}/AREA_{zm} = f(MLS_{zm}, COV_{zm}, X_m)$$

The first thing to note about this model is that it has a limited dependent variable. In many studies of land allocation or land change, a "land share model" based on the logit log-odds is estimated (Foley, 2004; Hardie and Parks, 1997). In such a model, the dependent variable would be specified as $\ln\left(\frac{y_i}{1-y_i}\right)$ where y_i is percentage of land area, as on the left hand side of equation (1). An advantage of the land share model is that the dependent variable is not bounded by zero or one, so the model can be estimated using OLS.

In the dataset there are many cases where $y_i = 0$, so the logarithmic transformation required by the land share model cannot be used. Instead, the percentage of land area that developed from 1995 to 2002 is used as the dependent variable, as shown in (1), and the model is estimated using the fractional logit specification of Papke and Wooldridge (1996). This becomes a general linear model with a logit link function.

The areal unit problem and units of observation

Theoretically the model is a probabilistic one based on the likelihood of land conversion of individual acres, undeveloped parcels, portions of zones, or portions of municipalities. This sentence reminds us that with geographic data, the researcher has the ability to choose the unit of analysis, and by extension sample size, merely by changing scale. This is known in geography as the "modifiable areal unit problem" (Openshaw and Taylor, 1979; Wong, 2009).

The "acre" is clearly not an appropriate unit of analysis for this study. It is smaller than the key behavioral unit: the undeveloped parcel or farm *circa* 1995, which cannot be identified in this dataset. The 2002 development status of individual acres in the dataset could be coded 0 or 1 in a standard logit model. However, the "behavior" of an individual acre is not independent of its neighbors, many of which are on the same farm. The degrees of freedom in such a study would also be arbitrarily large, leading to Type 1 error in the regression estimates.

This thesis takes a conservative approach to the areal unit problem, by selecting the unit of analysis as each unique combination of municipality and MLS-defined zone, which leads to a sample size in the hundreds. This choice is conservative in statistical terms because it reduces the degrees of freedom below what one would have in a study of development outcomes across rural parcels in 1995. However, larger spatial units have the compensating benefit of internalizing (and therefore eliminating) many spatial correlations. For this reason, no statistical adjustments for spatial correlation are included in this study.

Using the zone as the unit of analysis, the dependent variable in (1) is scale-free. Indeed, it treats each zone, however small, as completely equivalent to every other zone when estimating generalized relationships among the dependent and independent variables.

That would not be appropriate. The zones that emerged from the GIS analysis are highly skewed in terms of size. The very smallest ones are likely to be the result of GIS errors, or "slivers." For this reason, all of the regression models reported below will include the square root of zone size as an importance weight (IDRE, 2016).[1] This approach restores a key benefit of using individual acres or parcels as the unit of analysis: the true importance/prevalence of each type of zoning will automatically be reflected in the statistical analysis, but without generating an arbitrarily large sample size.

Handling of multi-level covariates

As equation (1) indicates, it is not quite correct to say that this thesis is conducted entirely at the scale of the "zone." An important set of variables, X_m, is measured only at the level of the municipality. Technically speaking, the degrees of freedom used for estimating these coefficients should not be in the hundreds, but only eighty-three. This fact is often ignored in regression analyses where individual observations are nested

[1] I experimented with dropping zones smaller than a certain threshold on the assumption that these are improper GIS artifacts. As long as the regressions include zone size as weights, this practice does not appreciably change any of the results. See data section below.

within larger, homogeneous entities that are hypothesized to have their own effects on the outcome.

The model shown in (1) is in fact a "multi-level" statistical model, whose main features are well understood by social scientists (see Singer, 1998; Bell, et al., 2013; Zhu, 2014). Continuing to use *z* for the zone level data and *m* for municipal level data, one can derive the multi-level fractional logit model as follows:

$$logit(Y_{zm}) = \beta_m + \beta_{zm} Z_{zm} + e_{zm} \quad (2)$$

where β_m is a municipal-specific intercept, Z_{zm} is a vector of zone level predictors (e.g., COV_{zm},), and β_{zm} is a vector of coefficients associated with Z_{zm}.

Municipal level effects on the dependent variable can be modelled stochastically as a function of municipal-level parameters, so that

$$\beta_m = \gamma + \gamma_m X_m + \mu_m \quad (3)$$

where γ is the municipal level intercept, X_m is the vector of municipal level covariates introduced above, γ_m is a vector of coefficients on X_m, and μ_m is the municipal level error term.

Substituting equation (3) into equation (2) gives:

$$logit(Y_{zm}) = \gamma + \gamma_m X_m + \beta_{zm} Z_{zm} + e_{zm} + \mu_m \quad (4)$$

What distinguishes this model from the standard logit is the presence of the municipal level error term, μ_m, which marks it out as a *random intercept* model. This multi-level model was estimated using the PROC GLIMMIX command in SAS, with an option to ensure that degrees of freedom are adjusted downward for the municipal-level covariates, where N=83.

Bias introduced by selection into the zoning treatment

Many studies in the area of development choice by land owners ignore selection bias which make them untrustworthy. This thesis uses a preliminary diagnostic test to justify the decision to ignore selection bias (please refer to section *Data collection technique; descriptive statistics* for diagnostic test results). There is no guarantee that this decision would be justified in any dataset other than my own.

Best described by Van Butsic, selection bias presents itself as a problem in zoning studies because zoning can be “endogenous in models of land conversion” (Van Butsic, 2011). The author states that in models of land development, zoning can induce a form of selection bias for two reasons. The first reason is that there are only so many factors that a researcher can observe, causing some unobservable factors to influence development and therefore influence zoning decisions, which presents a selection bias estimation problem (Van Butsic, 2011). The second reason is that “parcels that are placed in a certain zone might have different distributions of the underlying covariates than parcels placed in an alternative zone” (Van Butsic, 2011). In the treatment effects literature, this is a statement about “covariate balance.” Lack of covariate balance can make it a challenge to distinguish the effects of zoning policies from the effects of observed characteristics. A difference in normalized means test is performed below to justify the decision to ignore selection bias,

If it is assumed that all of the covariates are included in the dataset that might explain development outcomes (or zoning), then the evaluation of covariate balance becomes critical. The latest overviews of treatment effects techniques (Imbens and Wooldridge, 2009; Imbens and Rubin, 2015) suggest that this is best done using estimates of the normalized difference in covariate means. Figure 1 shows the formula that would be used for each covariate, where subscript 1 denotes the treatment group, and 0 the control group in the typical binary treatment setup; S is the sample standard deviation.

$$\Delta_X = \frac{\overline{X}_1 - \overline{X}_0}{\sqrt{S_0^2 + S_1^2}}$$

Figure 1 : Formula for normalized difference in covariate means, Imbens and Wooldridge, 2009

According to Imbens and Rubin (2015), the purpose of the metric shown in Figure 1 is "to assess whether the differences between the two distributions are so large that simple adjustment methods such as linear covariance adjustment, are unlikely to be adequate for removing most biases in treatment/control average differences, in settings where linearity may not hold exactly" (Imbens, 2015). The surprising implication of this statement is that if the normalized differences in covariate means are small enough, regular linear regression without any formal correction for selection bias becomes defensible. In the case of this thesis, one can then argue that the drivers of development that *also* affect zoning will be adequately controlled by simple regression. To put it another way, propensity score techniques work by improving covariate balance. If there is healthy covariate balance to begin with, then propensity score matching may not be necessary.

Data collection technique; descriptive statistics

To estimate the effects of the model, data obtained by a detailed GIS (geographical information system) composed of digitized zoning maps and land use cover maps prepared by the New Jersey Department of Environmental Protection (see figures 4 and 5) was examined. The GIS dataset contains eighty-three different municipalities in the New Jersey Highlands region. The New Jersey Highlands consists of parts of seven different counties in the northern New Jersey area. These counties are Bergen, Hunterdon, Morris, Passaic, Somerset, Sussex, and Warren, which are all captured in the dataset.

Figure 2: Distribution of developable areas in the study area by MLS in 1995

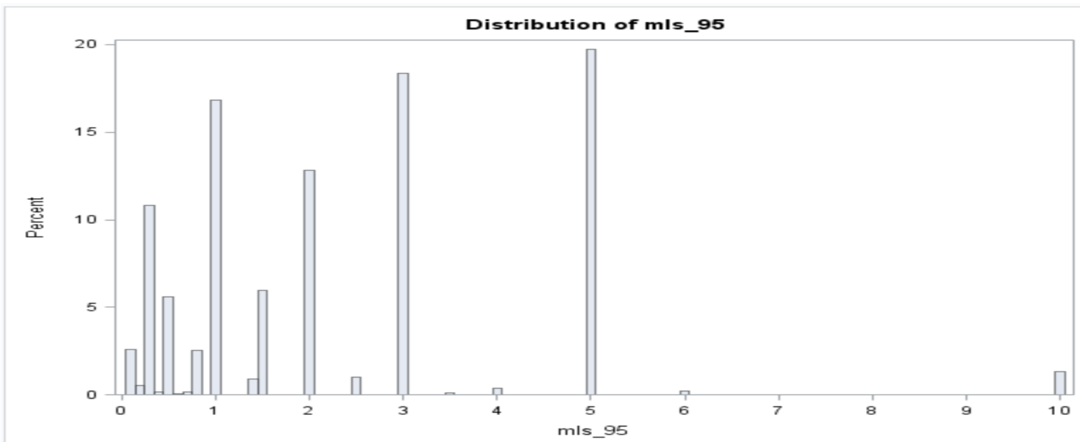

Table 1. Summary statistics from dummy variables created

Dummy variable name	Denotes	Frequency	Percentage
Z1	Minimum lot size (mls_95) less than or equal to 0.5 acres	85/373	22.79%
Z2	Minimum lot size (mls_95) greater than 0.5 acres and less than or equal to 1 acre	78/373	20.91%
Z3	Minimum lot size (mls_95) greater than 1 acre and less than or equal to 2 acres	21/373	8.31%
Z4	Minimum lot size (mls_95) equal to 2 acres	55/373	14.75%
Z5	Minimum lot size (mls_95) greater than 2 acres and less than 4 acres	63/373	16.89%
Z6	Minimum lot size (mls95) greater than or equal to 4 acres and less than or equal to 6 acres	54/373	14.48%
Z7	Minimum lot size (mls_95) equal to 10 acres	7/373	1.88%

Measured at the level of zoning group *

In the regressions reported below, variable Z1 will be omitted to avoid a perfect collinearity problem.

Table 2. Summary statistics of variables N=366

Variable	Variable Description	Mean	Standard Deviation	Minimum	Maximum
anyhiway	Presence of any major highway in municipality	0.5511811	0.4983556	0	1
chg_mls95_02	Extent to which zoning changed between 1995 and 2002	0.3158032	2.1033413	-0.975	30.0786184
medhhi89	Median household income in 1989, from US Census	56575.11	15355.35	34489	108486
mls_95	Minimum lot size for this zone in this municipality	1.3478652	1.5860991	0.0833333	10
nycdist	Distance from municipality centroid to Manhattan	39.5304372	11.8705423	21.9	61.96
pctfarm95	Percentage of developable acres that were in farm land cover in 1995	0.2106894	0.2456866	0	0.9999959
pctpres97	% of total muni acreage that was permanently preserved open space by 1997	0.1314058	0.1191424	0	0.4558491
popdens	Population density per square mile in 1995	992.2764079	1369.31	111.5768	10610
slopeper	% of municipality with steep slopes	5.6410568	3.7989172	0.0410737	15.85462
violent	Violent crime rate per 1000 (1989 and 1990 averaged)	0.6896175	0.6274553	0	6.95
zoneacres	total acres in the zone (municipality / mls_95 combination)	861.2314581	1564.63	25.3432328	11469.95
pctdev02	total development as a % of total land area in 2002	0.074788	0.0967705	0	0.7824617

The data allowed me to observe minimum lot sizes in each residential zone, and to deduct the number of acres converted from forest, grassland, or farmland to residential land between the years 1995 and 2002. The variables chosen for this thesis are variables that are believed to have either some influence on zoning, some influence on development, or a combination of the two. The variables medhhi89, anyhiway, nycdist, violent, slopeper, and popdens, were collected for use in Gottlieb, et al. (2012). These variables exhibited variation across municipalities (N=671 for these variables).

The variable medhhi89, median household income in 1989, is hypothesized to have a negative impact on development, assuming that "preservation of rural character and other environmental amenities is a luxury good" (Adelaja, 2009), and that affluent homeowners can slow down development by means that are both political and bureaucratic. The binary variable anyhiway, is hypothesized to be positive, inferring that the presence of a highway in a municipality will encourage development towards that area. Gottlieb (2012) justifies his decision to include the presence of highway in his regressions by quoting authors Boarnet who states that the presence of a highway is a "significant driver of demand by developers and homebuyers" (Boarnet, 1994). The variable distance to New York City, nycdist, is expected to be positive, assuming that the closer a municipality is located to New York City, the more development will occur, for reasons such as greater job opportunities in the city and the "well-known outward progression of postwar suburbanization" (Gottlieb, 2012). Violent, the variable measuring violent crime in a municipality, is hypothesized to have a negative effect on development, deducing that areas with higher crime rates will see less development. The variable slopeper, the percentage of a slope within a municipality, is hypothesized to be negative, presuming that areas with slope are more difficult to develop. Slopeper was included in Gottlieb's paper, and is deemed appropriate in this paper, because the variable "captures the effect of land that is difficult to develop" (Gottlieb, 2012). Popdens, the measure of population density in 1995, is estimated to be positive in the following regression models, on the assumption that the more residents in a municipality, the larger the need for development will be. Population density was chosen primarily on the assertion by Gottlieb that "start-year population density is commonly included in intra-metropolitan growth models" (Gottlieb, 2012).

The variables chg_mls95_02, mls_95, pctfarm95, pctpres97, and zoneacres are the product of a new GIS overlay analysis of data that were originally assembled by the Rutgers Center for Remote Sensing and Spatial Analysis, and then supplemented with data collected under an NSF grant (see Rudel, et al., 2011). More specifically, the variable mls_95 was created using GIS data on minimum-lot-size zoning in 1995 by dividing the acres in each minimum lot size by the minimum lot size of the specific municipality, providing a measure of zoned capacity in units (Gottlieb et al., 2012). Mls_95 is a numeric variable measured at the level of zone, and measures minimum lot size for a certain zone within a certain municipality by looking at dwelling units per acreage. The variables in Table 2 represent data on minimum lot size and land cover in 1995 and 2002, and exhibit variations across zones (N=693 for these variables). The main dependent variable in this thesis is Pctdev02. It measures total development as a percentage of total land area in 2002. Pctdev02 was created by dividing total acres developed for urban uses between 1995 and 2002 by total developable acres in 1995.

Pctdev02 was created with variables that are the product of the GIS overlay mentioned above (see Rudel, et al., 2011).

Through my work with the data it was discovered that there were eleven popular minimum lot sizes for development out of the thirty that were observed (see Figure 2). Figure 2 shows the percentage of acres with differing developable minimum lot sizes from the dataset. Dummy variables were created based on groups within Figure 2. The use of dummy variables will make it easier to identify non-continuous relationships. Table 1 shows how the thirty different minimum lot sizes were grouped into seven dummy variables Z1, Z2, Z3, Z4, Z5, Z6 and Z7.

To return to the selection bias problem mentioned in the *Econometric Issues* section, propensity score testing was conducted to ensure there was proper covariate balance between the variables in Table 3. The standardized difference in covariate means was estimated between zoning group 1 (MLS less than 0.5 acres) and zoning group 6 (MLS between 4 and 6 acres), reasoning that if any pair of treatment groups exhibits large differences, it should be these two extremes. Imbens and Rubin (2015) write, "as a rule-of-thumb, when treatment groups have important covariates that are more than one-quarter or one-half of a standard deviation apart, simple regression methods are unreliable for removing biases associated with differences in covariates, a message that goes back to the early 1970s but is often ignored" (Imbens & Rubins, 2015). Table 3 shows that all differences in covariate means in the dataset are less than one-half of threshold that would cause concern about the use of simple regression to control for endogeneity, according to Imbens and Rubin (2015). The covariates are fairly well balanced to start with, and so this thesis will include no formal corrections for endogeneity bias.

Table 3. Covariates are reasonably well balanced before applying a propensity score.

Covariate	Normalized difference in covariate means: Zoning group Z6 minus zoning group Z1
Percentage of land in zone that was farmed in 1995	0.109
Existence of any highway (0,1)	-0.055
Average farm size in 1992	0.014
Percent farm occupations in 1990	0.099
Median household income in 1989	0.028
Distance to New York City	0.113
Population density	-0.110
Percent land considered prime agricultural soil	0.116
Percentage change in residential parcel value 1980-1990	-0.006
Percent land in steep slopes	0.025
Violent crime rate	-0.067
Percent open space permanently preserved	-0.062

Means are weighted by size of zone. All but the first variable are municipal level.

The New Jersey Highlands descriptive statistics

As mentioned previously, the New Jersey Highlands is an area characterized by a large number of commuters, due to its proximity to New York City. A study conducted in 2002 by Phelps and Hoppe reported that the New Jersey Highlands are characterized by higher elevations that are dominated largely by forest land cover, most of which is privately owned (Phelps and Hoppe, 2002). Some key statistics from the same study found that in 2002 there were over 106,000 acres of land under agricultural cover in the Highlands and that the "size of most farms is in the 10 - 49 acre size class, and they are primarily located in Warren, Hunterdon, and the very eastern part of Sussex County in New Jersey" (Phelps and Hoppe, 2002). The study also noted an increase in population and housing units from 1990 to 2000, with a population increase of 10.5% from approximately 2.27 million to approximately 2.51 million, and a housing unit increase of

8.5% from 863,877 units to 938,987 units (Phelps and Hoppe, 2002). The Highlands specific characteristics allows for a unique analysis on land cover change in northern New Jersey.

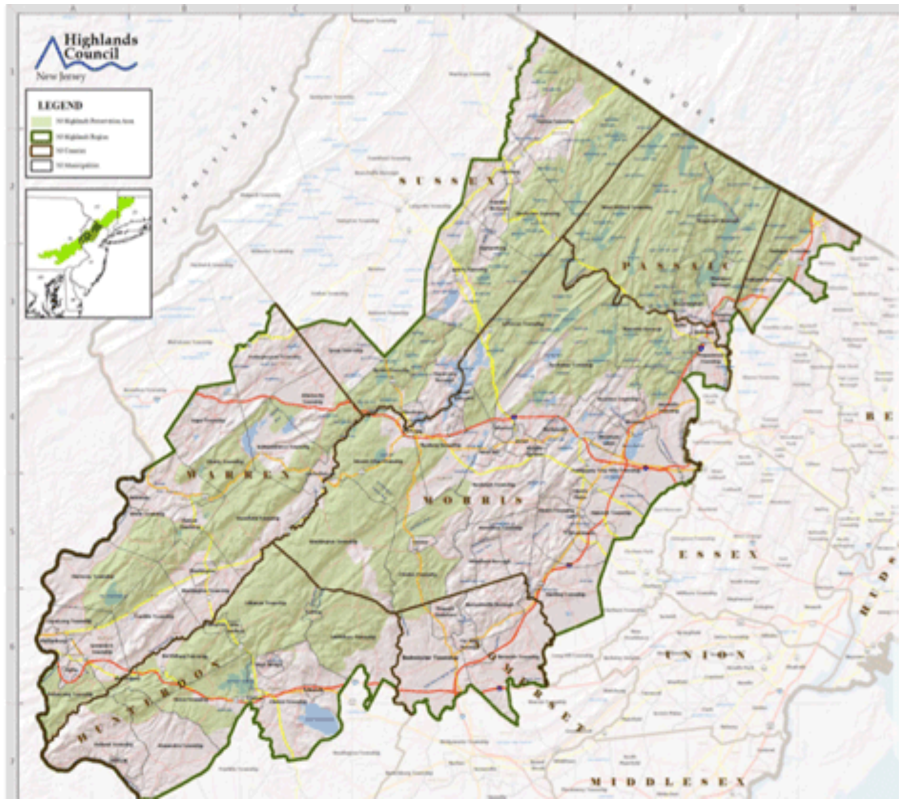

Figure 3. Highlands Council Map, a visual of the New Jersey Highlands (Johnson, 2014)

The map in Figure 3 (Johnson, 2014) shows the study area of this thesis, outlined in black, and gives the reader a better visual of which parts of the seven counties are included in the New Jersey Highlands region. The New Jersey Highlands has 859,358 acres located on 1,343 square miles (New Jersey Highlands Region General Information for Residents and Business Owners, 2008). This area also includes 88 municipalities, of which this thesis was able to provide data on 83.

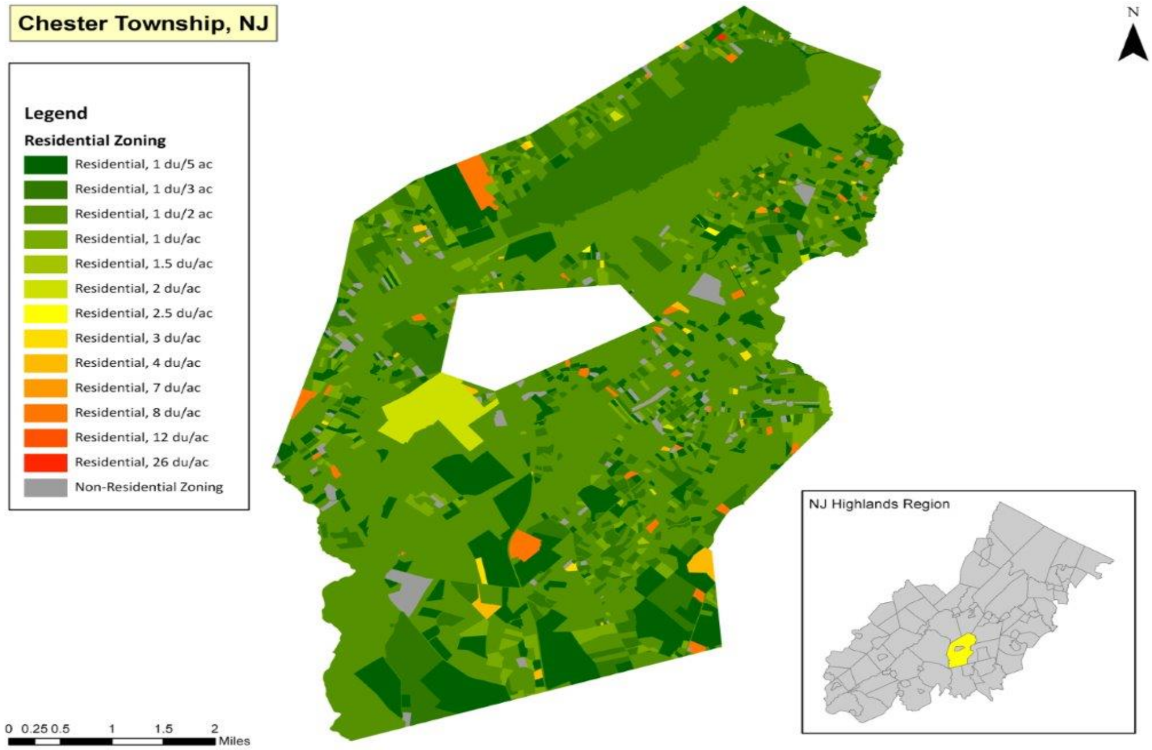

Figure 4. Chester Township Residential Zoning, GIS overlays of digitized zoning maps

To present the reader with a visual representation of the distribution of zones and land usage in one of the 83 municipalities of the study area, a map of Chester Township has been included (Figure 4). Figure 4 shows GIS overlays of digitized zoning maps that allowed analysis to identify where the most densely populated areas of the municipality are, versus the areas with larger acreage per unit. The map measures density as the amount of dwelling units "du" in a particular acreage size "ac", (see the legend on the left side of Figure 4 for specific measurements). By observing the map, the reader can see that Chester Township has the potential for urban sprawl, with many areas where one "dwelling unit" must be located on a five-acre parcel. There are a few areas on the map that show 7 dwelling units on one acre, but these areas are widely separated and do not appear to be in any type of spatial formation, but rather, appear randomly dispersed. The map in Figure 5 shows the same area of Chester Township in New Jersey, but allows the reader to more easily identify the type of land cover that certain areas are under, whether an area is under agricultural use, urban use, forest, water, wetlands or barren lands.

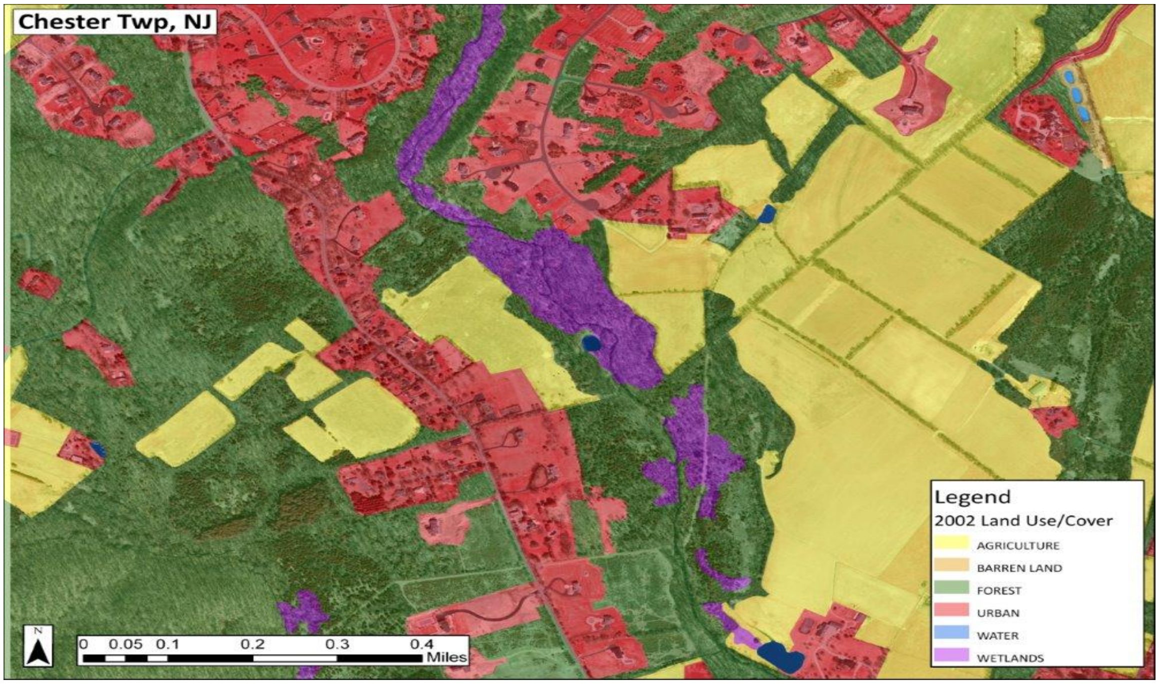

Figure 5. Chester Township land use-land cover map (NJ Department of Environmental Protection)

EMPIRICAL RESULTS WITH INTERPRETATION

The theoretical model hypothesized that the results would reveal monotonically declining or concave landscape development as a function of an increase from Z1 to Z7. The coefficients of the dummy variables Z2 through Z7 are negative and significant (view table 4) when the regression includes the variables pctfarm95, chg_mls95_02, anyhiway, medhhi89, nycdist, popdens, slopeper, violent, and pctpres97. All six zoning groups are different from the group Z1, and are statistically significant with P-values less than 0.1. They are significant between the interval 0.05 through 0.10 (significance values shown in table 5).

Distance to urban core (variable nycdist), discussed earlier in the theoretical section, was seen as a powerful driver in regards to landscape change, with a significant negative coefficient of -0.01806 (table 5). This coefficient indicates that the further away from the city a parcel of land is located, expressed in miles, the less likely it will be to develop, and vice versa if a parcel of land is closer to the urban core the likelihood of development is greater. The percentage of farm land in 1995 (variable pctfarm95) was also significant and positive, with a coefficient of 0.5495 (table 5). One would expect that land under farm cover is more easily developed versus land that is under forest cover, because farms typically are characterized by flatter slopes. The percentage of municipality with steep slopes (variable slopeper) was also significant and negative with a coefficient of -0.06501 (table 5). The percentage of slope in an area is directly correlated with the amount of development that will occur in that same area. As the slope increases in steepness, development decreases, due to the difficulty of developing on a slope. Finally, the variable (violent), representing the percentage of violent crime in an area, has a significant and negative coefficient of -0.2176 (table 5), signifying that the more violent crime in an area, the less development that will occur. The variable violent is measured as crimes per 1,000 residents in a certain municipality. The variables ch_mls95_02, anyhiway, medhhi89, popdens, and pctpres97 were found to be insignificant.

In another regression performed where mls_95 was used directly as a continuous variable instead of grouping mls_95 within seven dummy variables, it was seen that the policy variable of interest (mls_95) was significant and negative, with a coefficient of -0.2104 (table 4). This result indicates that areas with larger minimum lot sizes will see less development and vice versa, areas with smaller minimum lot size will see more development. Because the squared term (mls_95*mls_95) is not significant a concave figure is not apparent, but rather the dependent variable declines continuously as a function of mls_95. In the same regression it was again viewed that slopeper and violent were significant and negative (table 4).

Theory would suggest that with a higher population density one would expect to see more development, however here it is viewed that landscape change is insignificantly related to population density (the variable popdens) holding other factors equal. With the data one would also expect to see denser communities closer to New York City, and that they would be engaged in denser zoning. A correlation matrix for the independent variables showed that both of these things are true. Collinearity might be partly responsible for the insignificant coefficient on the population density variable.

Table 4. Regression running mls_95 as a continuous variable

Solutions for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-0.7999	0.8740	73	-0.92	0.3630
pctforest95	-0.2381	0.3020	281	-0.79	0.4311
mls_95	-0.2104	0.07277	281	-2.89	0.0041***
mls_95*mls_95	0.01306	0.01080	281	1.21	0.2275
chg_mls95_02	-0.01989	0.04153	281	-0.48	0.6323
anyhiway	0.1438	0.1630	73	0.88	0.3806
medhhi89	-7.39E-6	6.812E-6	73	-1.08	0.2818
nycdist	-0.01333	0.009954	73	-1.34	0.1846
popdens	8.925E-6	0.000069	73	0.13	0.8971
slopeper	-0.07292	0.02537	73	-2.87	0.0053***
violent	-0.2204	0.1297	73	-1.70	0.0935*
pctpres97	-0.2710	0.7559	73	-0.36	0.7209

*significant at 90% level; **significant at 95% level; ***significant at 99% level.

Table 5. Regression run with the inclusion of dummy variables

Solutions for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-1.1038	0.7421	74	-1.49	0.1412
z2	-0.2160	0.1100	164	-1.96	0.0513*
z3	-0.4388	0.2418	164	-1.81	0.0714*
z4	-0.2578	0.1441	164	-1.79	0.0754*
z5	-0.5124	0.1351	164	-3.79	0.0002***
z6	-0.6327	0.1535	164	-4.12	<.0001***
z7	-1.0655	0.5446	164	-1.96	0.0521*
pctfarm95	0.5495	0.3085	164	1.78	0.0767*
chg_mls95_02	-0.05791	0.07427	164	-0.78	0.4367

Table 5. Regression run with the inclusion of dummy variables

Solutions for Fixed Effects

Effect	Estimate	Standard Error	DF	t Value	Pr > |t|
anyhiway	0.1489	0.1551	74	0.96	0.3402
medhhi89	-5.77E-6	6.503E-6	74	-0.89	0.3782
nycdist	-0.01806	0.009411	74	-1.92	0.0589*
popdens	8.216E-6	0.000066	74	0.12	0.9012
slopeper	-0.06501	0.02417	74	-2.69	0.0088***
violent	-0.2176	0.1118	74	-1.95	0.0555*
pctpres97	-0.2189	0.7207	74	-0.30	0.7622

*significant at 90% level; **significant at 95% level; ***significant at 99% level.

The regression results above supported that areas with smaller minimum lot sizes had a higher percentage of land that developed in 2002. It can be concluded that smaller lots are more preferential for residential development, due to affordability and possibly issues with how difficult it is to upkeep property on larger lots. To get a better visual of the decline in development as the size of the zone increases see figure 6. Figure 6 illustrates the actual percentage of land developed in each zoning group, dummy variables Z1 through Z6. Between 1995 and 2002 the most development occurred in zoning group 1 (minimum lot size less than or equal to 0.5 acres) with approximately 7.5 percent of the area in this zoning group developing. The popularity of development in Z1 is most likely is due to reasons of affordability. Smaller parcels of land tend to be less expense. Areas under group Z2 (greater than 0.5 acres, and less than or equal to 1 acre) also saw a higher percentage of development when compared to areas with larger MLS, most likely explained by the same reasons Z1 saw a higher percentage of development.

The results do not align with a monotonically declining or a concave figure, however due to the negative coefficients the results show a downward trend, with an anomalous bump at Z3 (figure 6). Z3's lack of popularity for development could be due to the fact that real estate markets prefer even numbered lot sizes, minimum lot sizes of 2 acres as opposed to minimum lot sizes of 1.5 acres. Even relative to zoned capacity, then, more units were likely developed in zoning group Z4 than in Z3. Including the dip at Z3 there is still general sense of decline throughout.

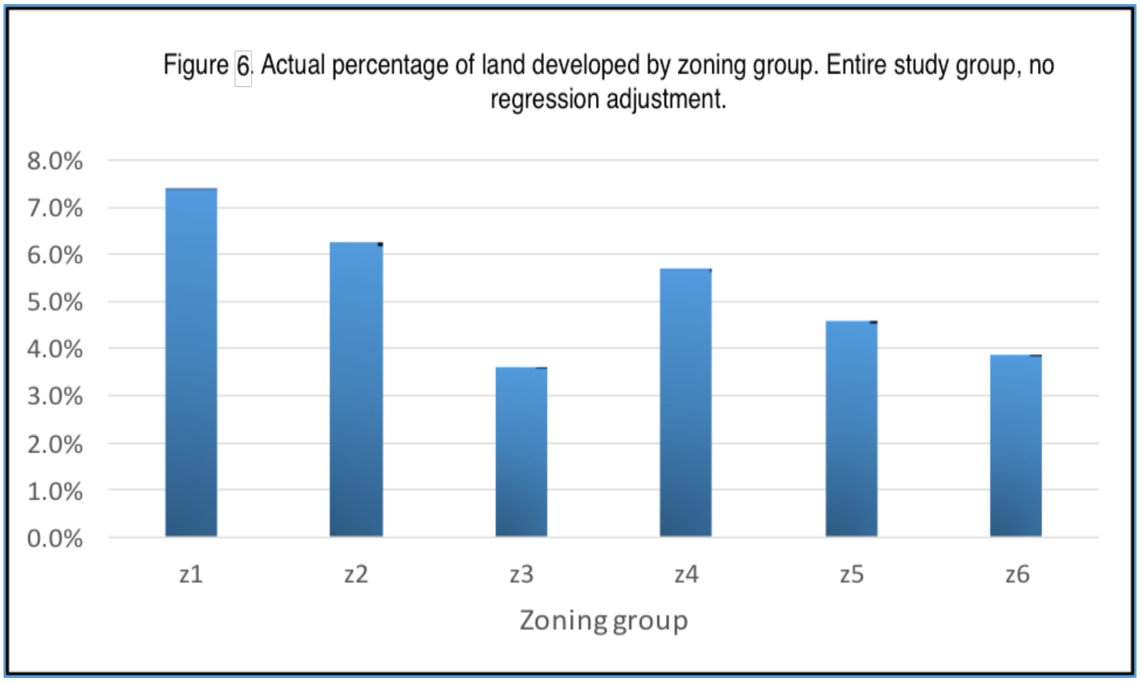

Figure 6. Actual percentage of land developed by zoning group, consistent with regression results (X axis represents the percentage of land developed in 2002, Y axis represents the zoning group described more in depth in table 1).

To support that the results are truly capturing what is occurring, various regressions were performed to ensure robustness. After performing thirty-three different regressions on the data, the robustness tests confirmed that the reported regression results are strong and robust (see table 5). The variables z2, z3, z4, z5, z6, z7, pctfarm95, nycdist, slopeper, and violent all remained significant and kept their coefficient reported in the regression results in table 5, whether it be negative or positive at least 72 percent of the time, if not more (see individual results in table 5). Occasionally the variables were not significant. To test for robustness, variables from the dataset that were not included in the reported regressions, such as resacres02 (acres in the zone that were developed for residential use in 2002), dempstd (growth in jobs in reference community and surrounding communities 1990-1995), mundem (percent of municipal governing body that was Democrat in 1994) and ownocc (percent residents who were owner occupiers in 1990, US Census). Throughout the regressions to test for robustness key variables were eliminated such as the zoning groups or variables seen in tables four and five, while adding variables that were not included in those regressions, conducting thirty-three different tests. Overall it can be said with confidence that the results are robust.

Table 6. Robustness Tests (33 tests run altogether)

Variable	Original Regression Coefficient Sign	Significance between interval 0.05-0.10	Amount of times variable coefficient remained consistent with regression results
Z2	Negative	Significant	25
Z3	Negative	Significant	25
Z4	Negative	Significant	26
Z5	Negative	Significant	31
Z6	Negative	Significant	29
Z7	Negative	Significant	24
Pctfarm95	Positive	Significant	29
Chg_mls95_02	Negative	Not Significant	31
Anyhiway	Positive	Not Significant	31
Medhhi89	Negative	Not Significant	24
Nycdist	Negative	Significant	24
Popdens	Positive	Not Significant	25
Slopeper	Negative	Significant	30
Violent	Negative	Significant	26
Pctpres97	Negative	Not Significant	28

CONCLUSION

This thesis offers a unique contribution to the question of whether minimum lot sizes cause urban sprawl, defined for present purposes as conversion of the landscape away from rural use/rural cover. Where most zoning studies previously conducted by economists examine price as the dependent variable of interest, this thesis looks at developed acres as a percentage of all acres at risk to develop. The actual change in residential development between 1995 and 2002 was observed across a set of homogenous zones. The hypothesis that large lot zoning reduces development, defined as a percentage of acres converted, was confirmed. It was observed that a higher percentage of land developed with smaller minimum lot sizes, and this figure declined gradually as minimum lot size increased.

In terms of implications for public policy, establishing minimum lot sizes appears to be an effective tool for planners -- if their only goal is to suppress land development. Although the regression results show that high minimum lot sizes help to delay development; they may or may not preserve rural character, depending on how that phrase is defined. The future of suburban development is inherently uncertain, so understanding how land use regulations influence urban sprawl is key to help zoning official better prepare for the future.

Shortly after the data period had ended the entire New Jersey Highlands area was put under a regional planning board. Following the creation of the board the Highlands Conservation Act of 2004 (P.L. 2004, c.120), was signed into law to protect forest cover and conserve the watersheds in the Highlands that provide clean drinking water to millions of people (Gilbert, 2004). The act divided the region into two areas, the preservation area of approximately 415,000 acres, and the planning area of approximately 444,000 acres (New Jersey Highlands Region General Information for Residents and Business Owners, 2008). The Conservation Act, along with minimum lot sizes policies in the Highlands, attempted to maximize planners' ability to stop urban sprawl, and to guide development to locations that would best protect the state's water supply. Residents and business owners in the Highlands were originally worried that the act would put a halt to all types of development in the area, however the committee that created the act recognized the importance of the regional economy and sought to "ensure protection of resources by focusing growth in areas that are already developed" (New Jersey Highlands Region General Information for Residents and Business Owners, 2008).

The reader may find themselves wondering what land use changes occurred in the New Jersey Highlands following the time period of analysis from 1995 to 2002 examined in this thesis. John Hasse and Richard Lathrop provide a good summary of what happened by studying urban sprawl and open space loss in New Jersey from 1986 to 2007. Their research found that between 2002 and 2007 "overall trends of urban development have remained robust while open space and important resources continue to be lost at an equally rapid pace" (Hasse and Lathrop, 2010). The study also found that "urban development has continued to gain momentum up through 2007 in New Jersey. Between 2002 and 2007 there were 16,061 urbanized acres per year, up from the 15,123 urbanized acres per year between 1995 through 2002" (Hasse and Lathrop, 2010). While these numbers provide a good impression of how sprawl is still an ongoing issue, it does not accurately express the exact loss of important resources to sprawl. The research article goes on to further break down sprawl by land use changes, indicating that New

Jersey lost 28,652 acres to sprawl from agricultural lands and 42,451 acres to sprawl from forest land (Hasse, 2010). These numbers show that although planners implemented the Highlands Conservation act of 2004, the policy may not be as effective as intended. With the goal of the policy to conserve forest lands, it is surprising to see that statewide, more acres of forest are being converted to residential use than any other type of undeveloped land. That being said, much of the period examined in this 2010 study was before the Highlands Act was fully implemented.

The research article "Urban Sprawl in the United States: 1970 to 2010" also provides the reader with some statistics on how urban sprawl remains a continuing issue after 2002. Written by Russell Lopez, it demonstrates how sprawl is on the rise, not just here in New Jersey, but all across the country. A "national sprawl index" has increased from 36.81 in 1970 to 50.60, a 37% increase in 40 years (Lopez, 2014). Although the article is not specific to New Jersey, it does stress that planners need to have sprawl on their radars.

A more recent study conducted by New Jersey Future, which monitors Smart Growth programs and their success or failure in New Jersey, stated that "population losses are now widespread across the exurban fringe and rural areas…most municipalities having fewer people than they had in 2008" (Evans, 2016). Counties that were included in this thesis, such as Somerset, Sussex, and Hunterdon, saw losses in population immediately after the Great Recession. Bergen and Passaic have actually seen population gains, most likely due to their proximity to New York City (Evans, 2016). This research shows that more recently, a transition from the exurban fringe to areas closer to New York City has occurred, and this could be in part due to consumer preferences, minimum lot size imposition restrictions, and zoning policies implemented to curb urban sprawl (Rudel, et al., 2016).

Although the dataset presented in this thesis is comprehensive, it would be wise for future research to examine counties that are not inside of any metropolitan area (all of New Jersey's counties are metropolitan). With distance to New York City being such an important explanatory variable, it would be interesting to examine an area that lacks this kind of influence on development. Another useful study might focus on the New York State Highlands as the study region. Many variables that were used in this study would remain valid, but a different state-level regulatory regime might have different effects. Finally, as in Carrion-Flores and Irwin (2004), we could examine a state or area where not every acre is zoned, unlike in New Jersey. Future research can help settle disagreements among farmers, non-farm homeowners, and planners regarding the effects of local land use policies on urban sprawl.

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