Expanding the Monocentric Model

A Fixed Effects Approach to the Determination of Urban Land Values

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Abstract

In this paper I explore the determinants of urban land value over time. Expanding on Edwin Mills' [12] version of the Monocentric model, I use panel data for the decade years from 1910 to 1970 for the city of Chicago to relate the price per frontage foot of 40 locations with the distance to the central business district, racial diversity, proximity to an elevated rail station, and a measure of wealth in the economy. I use a fixed effects approach by including dummy variables corresponding to the 40 test locations. The inclusion of these dummy variables allows me to isolate the true marginal influences of the other explanatory variables, something that previous studies fail to accomplish. The results are startlingly contradictory to commonly held beliefs. Distance has the expected negative effect on land values, but with mixed significance. Racial prejudice, the presence of a transit stop, and the overall wealth of the economy are not significant determinants of land value. The significant determinants of land value in my model are the location-specific dummies, which capture the unique and constant attributes of a location over time. These dummy variables show that direction is an important determinant of land value, contrary to Mills' theory.

1. Introduction

The goal of this paper is to estimate urban land values based on a location's distance from the central business district (CBD), the racial make-up of people living in its surrounding area, the existence of a nearby transit station, the overall wealth of the economy and the characteristics that are constant and unique to that location. An understanding of the factors determining land value is important for urban planners, mass transit officials and the general public.

Edwin Mills' study "The Value of Urban Land," [11] one of the earliest studies to propose the Monocentric model, states that there is an inverse relationship between a location's land value and its distance from the CBD. Mills also concludes that as a location's distance from the CBD increases, its rent decreases quickly at first, and at a slower rate as it gets farther away from the center. [12] This highlights the two main points that have guided the theory of urban land rents. First, land should "soak up" all remaining revenues after other inputs have been purchased. Second, land rents should dictate the allocation of land because the price of land should equal its marginal product when markets are competitive. [11] Mills only incorporates a location's distance to the CBD, not its direction, into his model.

Mills makes two assumptions about the interaction in an urban environment in order to develop an explanatory model for the price of land with respect to its distance from a certain point. First, Mills assumes a "a plain, homogeneous world," where it is possible for a particular firm to achieve increasing returns to scale and thus encourage other firms who may buy products from, as well as sell to, this firm to move nearer. Mills refers to this interaction as a "vertical relation" between firms. Secondly, an individual parcel of land may possess certain characteristics that make its location advantageous as compared to another parcel of land that lies at a similar distance from the CBD. One such advantage may be an increased availability of transportation, the idea that inspired this study.

My model deviates from Mills' in two important ways. The first difference is the selection of independent variables. While we both use the distance from a plot of land to the CBD as an explanatory variable, Mills uses five dummy variables that correspond to the zoning classification of a particular piece of land. I do not implement such qualitative explanatory variables but instead include the more numerous aforementioned independent variables.

The other difference is our respective data sources. We both use a popular data source for urban economic analysis [10, 11]: "Olcott's Land Values Blue Book of Chicago." This data source registers the price per frontage foot for all of Chicago's metropolitan area on an annual basis and lists each location's distance from the corner of State and Madison, its proxy for the CBD [13]. In addition, Mills selects locations along eight major streets in the Chicago area, all for one year. On the other hand, I select a sample of 40 addresses from this set and track their fluctuation in land value for 1910, 1920, 1930, 1940, 1950, 1960 and 1970, therefore developing 280 data points. Since I am interested in land's proximity to Chicago's elevated train, (the"El") I choose a sample that includes addresses that are always, sometimes and never "near" (to be defined later) an "El" stop.

Malcom Getz [5] examined the effect of an improvement in transportation on land values. To do this, he divided a "plain homogenous space" into two sectors, one for residence and one for employment. After imposing a few strict assumptions, namely that both the demand for the final product and the supply of labor are perfectly elastic, Getz concludes that the effect of an improvement in transportation is essentially indeterminate. When the mode of transportation improves, the residential sector grows spatially, as does the production sector, offset only slightly by the infringement on its region by the burgeoning residential sector. However, when he relaxes the assumptions and allows the elasticities to fluctuate, Getz is able to draw more definitive conclusions. The more elastic the final demand for the production sector's good, the greater the impact an improvement in transportation has on land rents. The main difference between my study and Getz's is that I do not divide Chicago into these two sectors.

D.N. Dewees [4] studied the relationship between land value and distance to the CBD in Toronto. He also investigated the relationship between land value and distance to a transit station, by treating an individual station as a CBD for its surrounding area. Every year transportation becomes more rapid compared to walking speed. Because Dewees believes that the primary way to get to the nearest transit station is by walking, he evaluates the change in land rents due to a change in distance from the nearest transit station, not the distance from that transit station to the CBD. Dewees concludes that land values decline for locations that are farther away from a station and that the effect is noticeable up to one third of a mile.[1]

John McDonald and H. Woods Bowman [9] noted that the correct functional form for the Monocentric model had not come under serious scrutiny. The authors asserted that the best functional form, as based on adjusted R^2, is one where the explanatory variable

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[1] Therefore, I will define "near a transit station" to be within one third of a mile.

of distance to CBD is raised to the fourth power. Admittedly, however, they offered little theoretical backing for why this might be the most appropriate model. One note of importance for my project is that the authors questioned the validity of the Olcott data. They were concerned that because the values are assigned by an appraiser, there is a large chance for error and bias. However, if there were error, it would appear in the dependent variable (land value) and thus not lead to bias in the estimation of the parameters. Also, they noted that any bias due to the ethnicity, age or other characteristics of the appraiser, would be unlikely to lead to a systematic error in the measurement in the data.

Clifford Kern [8] examined a new topic in relation to land rents that sharply differs from the previous literature. He reevaluated a study performed by John Yinger [16] that focused on the way that fluctuations in the racial make-up of an area affect *its* land values. Attempting to generalize Yinger's conclusions, Kern analyzes the *interrelations* of neighborhoods' land values and their minority populations. This idea seems more realistic since a homeowner is likely to be concerned not only with his or her particular neighborhood, but also with a larger area, perhaps the entire city. Kern notes that because landlords work in a competitive environment, they are unlikely to change the racial composition of an area, something that might change the expected future returns of an area's land rents. Therefore it makes sense for them to sell to the highest bidder, black or white. Despite the unbiased profit maximizing behavior of landlords, the land's occupants are subject to their opinions and biases as they attempt to maximize their own utility. Kern analyzes locations that begin as segregated areas as well as those that start as integrated areas. Four of Kern's most important conclusions are:

> 1. Whenever preference for white neighbors is stronger among whites than among blacks, integrated equilibrium is unstable, but there is a stable segregated equilibrium.

2. Whenever preference for white neighbors is stronger among blacks than among whites, no segregated equilibrium is possible, but there is a stable integrated equilibrium.

3. In an integrated equilibrium, all sites have identical racial composition. Therefore, racial composition has no effect on the equilibrium rent-distance function.

4. In a segregated equilibrium where whites prefer whites as neighbors and blacks prefer blacks as neighbors, equilibrium rent on the white side of the border may exceed, equal, or fall short of the rent on the black side. In a segregated equilibrium where both races prefer white neighbors, the equilibrium rent on the white side will always exceed that on the black side in the absence of discrimination.

Since Chicago was one of the largest cities in the United States during the 20th century, it attracted many ethnicities and races. If this awareness for a city as a whole was apparent in 1981, it is even more important now, due to the increased mobility and increased populations that have been the natural consequences of the past 22 years. Therefore I include the percentage of blacks living in the neighborhoods of my 40 test locations as an explanatory variable. Of the options for prejudice and land rents that Kern presents, I find the notion of a segregated area where whites are more prejudiced against blacks than blacks are against whites as the most plausible and therefore will use it as a basis for my predictions involving the influence of this independent variable.

Daniel McMillen [10] attacked the previous methods for estimating land values claiming that too often researchers sample from both “urban” and “non-urban” areas. When this happens, McMillen stated that the elasticity of housing demand in the urban area is estimated to be flatter than it truly is. He also said that, “by 1928 it is likely that all available observations are urban.” The most important way that McMillen’s article relates to my study is that according to his theory I do not have to worry about my data “not being urban” because most of it is from after 1928.

Jeremy Atack and Robert Margo, [1] using land value data in the city of New York for most of the 19th century, before it was a fully developed area, concluded that over time the rent gradient becomes flatter, and that the adjusted R^2 of their hypothesized bid-rent function becomes lower. Two possible explanations for their findings are a greater difference in use of land as time passes and a CBD that is actually moving. Their article adds a new consideration to my study since they claim that the main effect described by the Monocentric model, namely that land values decrease at a diminishing rate as distance from the CBD increases, is realistic, but weakens over time.

2. Model Development and Testable Hypotheses

The factors that I expect to be the most important in explaining land value fluctuations are the distance from a location to the CBD, the racial make-up of that location's inhabitants and the location's proximity to a transit stop, specifically an elevated rail station. I also expect a macro-variable, the Dow Jones Industrial Average, to have considerable influence on land value since it is a proxy for the public's wealth. Finally, a corner's attributes should also be included since they can affect the desirability of an area. However, such detailed information is unavailable. Therefore, while I cannot control for time-varying unobserved corner characteristics, I do include fixed effects to capture time-constant corner characteristics. The constant attributes of a particular corner, not explicitly represented in the model by an explanatory variable, are included as 36 dummy variables. Each one corresponds to one of 36 locations, since I use four locations as my "benchmark" case[2].

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[2] The onset of perfect multicollinearity mandated the use of more than one corner for a "base case." The four benchmark corners were chosen because they are all located near each other and thus have the highest probability of having the most similar attributes.

The land value function is

(1) $$LV_{it} = f(D_i, \%Black_{it}, T_{it}, DJIA_t, C1, C2, \ldots, C36)$$

where LV_{it} is the land value of a particular location *i* at time *t*, measured in constant 1982 dollars.

Distance (D_i)

Based on Mills' article, referred to earlier, I hypothesize that the marginal change in land value due to an increased straight-line distance from the CBD is negative, as indicated by the following derivative.

$$\frac{\partial LV}{\partial D} < 0$$

The effect that distance has on land value should diminish as the distance from the CBD becomes greater, as indicated by a positive second derivative of land value with respect to distance.

$$\frac{\partial^2 LV}{\partial D^2} > 0$$

A model that incorporates these two ideas is one of the log-log form:

$$\ln LV_{it} = \beta_0 + \beta_1 \ln D_i.$$

When this functional form is chosen,

$$\frac{\partial LV}{\partial D} = \beta_1 (LV/D).$$

Because LV/D is positive, β_1 must be negative, in order for the first derivative to be negative, and this will be the first hypothesis that is tested. In this functional form the elasticity of land value with respect to distance, β_1, should also be negative. The second derivative in the log-log form is

$$\frac{d^2LV}{dD^2} = \beta_1(\beta_1 - 1)\frac{LV}{D^2}.$$

Since it was assumed that β_1 is negative, it follows that the second derivative is always positive, which is consistent with the theory of the diminishing influence of distance.

I do not utilize the quadratic form because I believe that the elasticity of land value with respect to distance is constant. I do not choose the log-lin form because I believe that the elasticity of land value with respect to distance should be constant and not increase as distance becomes greater.

Racial Composition (%Black$_{it}$)

This variable is the proportion of a neighborhood's population that is black. In order to predict the effect that a change in the percent of an area's population that is black would have on its land values, I make two beginning assumptions about the prejudices of the people engaging in the purchase and sale of urban land. The first is that the sellers of land are competing in a perfectly competitive market, as Kern stated, and therefore act in a profit-maximizing manner. The second assumption is that whites and blacks prefer living with whites, but blacks are not prejudiced against living with other blacks. Therefore, the only prejudice that may cause a difference in land rents is that due to the buyers of land, not the sellers of land.

With these two assumptions, consider a totally white neighborhood. Since blacks are not prejudiced against living with whites, at some point blacks may choose to move into this all-white area. At this time, some white owners will desire to leave the area since they *are* prejudiced against living with blacks. The result is an increase in the supply of land due to "white flight." The increase in the supply of land, *ceteris paribus*, would decrease the price of land, thus making it more affordable and would encourage more blacks to move into the neighborhood while whites would not choose to move into the area despite its decreased rent. Land values in the area would continue to fall until all of the prejudiced whites had left the area. These assumptions lead to the expectation that an increase in the percentage of blacks in an area will cause the price of land in that area to fall. Therefore,

$$\frac{\partial LV}{\partial \% Black} < 0.$$

The second derivative should be positive because the price of land will not decrease indefinitely, although it may approach a zero rent. Another less drastic case that leads to the dampening of the fall in the price of land as the percentage of blacks increases is the assumption that blacks are indifferent towards living with other blacks. An increase in the percentage of blacks, once that percentage has reached a certain threshold, may not cause the price of land to decrease further. This is because further increases in the percentage of blacks living in an area will not reduce the demand for land. Therefore,

$$\frac{\partial^2 LV}{\partial \% Black^2} > 0.$$

The above theories about the 1st and 2nd derivatives hold when the log-reciprocal form is used. That is,

$$\ln LV_{it} = \beta_0 + \ldots + \beta_2 \frac{1}{\%Black_{it}}.$$

Therefore,

$$\frac{\partial LV}{\partial \%Black} = -\beta_2 \frac{LV}{(\%Black)^2},$$

and,

$$\frac{\partial^2 LV}{\partial \%Black^2} = B_2 LV \left[\frac{B_2}{(\%Black)^4} + \frac{2}{(\%Black)^3} \right].$$

If β_2 is greater than zero, the first derivative is negative and the second derivative is positive.

Transit Stop (T_{it})

This dummy variable indicates the existence of an elevated rail (the "El") stop near a particular location in a given year. It takes on a value of 1 if there is a stop within a 1/3 of a mile of a corner, and it equals zero otherwise. If the cost of commuting were to fall, *ceteris paribus*, land values should rise. Therefore, the marginal influence of being close to a transit stop on land value should be positive. This is because lower land values compensate for increased distances from the CBD, essentially making up for increased commuting costs. However, if two corners are same distance from the CBD, yet the cost of commuting from one to the CBD is cheaper, the location with the cheaper transport should cost more. Because the effect of mass transit is incorporated as a dummy variable, the relationship between land value and the existence of an "El" stop is modeled in a log-lin form,

$$\ln LV_{it} = \beta_0 + \ldots + \beta_3 T_{it}.$$

In this functional form,

$$\frac{\partial LV}{\partial T} = \beta_3 LV.$$

β_3 must be greater than zero for the marginal influence to be positive.

The semielasticity of land value with respect to the absence or presence of a transit stop is [6, 7]

$$(e^{B_3} - 1)(100).$$

This is expected to be positive and constant since the presence of a transit stop should have the same percentage increase on land value at one corner as it does at another corner. This will be true if β_3 is positive.

Dow Jones Industrial Average ($DJIA_t$)

The Dow Jones Industrial Average serves as a proxy for the public's wealth. Assuming that people devote a certain percentage of their wealth to land, as the public becomes wealthier, more land will be demanded, which will drive up the price of land per frontage foot, for a given supply of land. The second derivative should be negative, indicating that the effect of rising wealth on the value of land is somewhat muted at higher levels of wealth. In essence,

$$\frac{\partial LV}{\partial DJIA} > 0,$$

and,

$$\frac{\partial^2 LV}{\partial DJIA^2} < 0.$$

In addition, I believe that as the public's wealth rises by one percent, the price of land will rise by a constant percentage, regardless of the amount of wealth in the economy. This implies that the elasticity of land value with respect to wealth is a constant. One form that represents my assumptions about the 1st derivative, 2nd derivative and elasticity is the log-log form,

$$\ln LV_{it} = \beta_0 + ... + \beta_4 \ln DJIA_t.$$

Furthermore, my prediction a positive first derivative and a negative second derivative implies,

$$0 < \frac{DJIA}{LV} \cdot \frac{\partial LV}{\partial DJIA} = \beta_4 < 1.$$

This is reasonable because as people become wealthier, they devote more money to land investments, and so although one may not know whether the effect of an increase in wealth on land prices is elastic, inelastic or unit elastic, it should always be positive.

Corner Dummy Variables (C1,..,C36)

The final variables in the model are the 36 location dummies that control for the effects that a location's unobserved specific surroundings and amenities have on its land value. These characteristics must remain constant over the 60-year period in order to be captured by the dummy variables. A dummy variables takes on a value of 1 when the location it corresponds to is being considered, and 0 otherwise. As noted earlier, four locations are not included since they serve as the "benchmark locations" for the model.

One observed characteristic of a corner that will not change over time is its direction from the CBD. I am including direction from the CBD as an independent variable to test Mills' theory that only a location's distance to the CBD will affect its land value. Since my base four corners are all north of the city, I can group the other corners into south or west of the CBD to test if their direction from the CBD is a determinate of their land value.

Another important hypotheses involving these dummy variables is to see if individual corners affect land value in ways that are statistically different from that of the base case. Here I will take each corner's parameter estimate and use a two-sided t-test to see if its effect on land value effect is statistically different from zero.

It is necessary to reiterate that I am only speaking of characteristics that remain constant for a corner over the 60-year period. Those features of a corner that have an effect on land value, but change over time, are captured in the error term.

The Model

My main model is represented in equation (2). Note that D1920 through D1970 are dummy variables taking on a value of 1 for their year and 0 otherwise. Dow Jones Industrial Average is introduced as a single variable because it does not vary within a year. The corner dummy variables are not included by year since they capture the unique aspects of a corner over the entire 60-year period.

$$
\begin{aligned}
(2) \qquad \ln LV_{it} = {} & \phi_0 + \lambda_1 \ln D_i + \lambda_2 D1920 \ln D_i + \lambda_3 D1930 \ln D_i + \lambda_4 D1940 \ln D_i + \\
& \lambda_5 D1950 \ln D_i + \lambda_6 D1960 \ln D_i + \lambda_7 D1970 \ln D_i + \delta_1 \frac{1}{\%Black_{it}} + \\
& \delta_2 D1920 \frac{1}{\%Black_{it}} + \delta_3 D1930 \frac{1}{\%Black_{it}} + \delta_4 D1940 \frac{1}{\%Black_{it}} + \\
& \delta_5 D1950 \frac{1}{\%Black_{it}} + \delta_6 D1960 \frac{1}{\%Black_{it}} + \delta_7 D1970 \frac{1}{\%Black_{it}} + \chi_1 T_i + \\
& \chi_2 D1920 T_{it} + \chi_3 D1930 T_{it} + \chi_4 D1940 T_{it} + \chi_5 D1950 T_{it} + \chi_6 D1960 T_{it} + \\
& \chi_7 D1970 T_{it} + \alpha_1 \ln DJIA_t + \tau_1 C1 + \ldots + \tau_{36} C36 + \varepsilon_{it}
\end{aligned}
$$

This model allows for the marginal influences of distance, the percentage people living in a neighborhood that are black, and transit to vary over time. *A priori*, I cannot determine whether or not this is the case. Therefore, I will use subset F-tests to determine whether the effects of the above variables vary over time. If one of them does not, I will collapse its series of year-specific variables into a single explanatory variable for that factor. Next, I will test to see if any of the explanatory variables are unnecessary and if there is a systematic change in the influence of the variables whose year-specific effects remain in my model.

3. Data and Statistical Assumptions

Data

The price per frontage foot for 400 intersections in Chicago and their distance from a designated CBD for 1910, 1920, 1930, 1940, 1950, 1960 and 1970 come from Olcott's Blue Book of Land Values for the city of Chicago. [13] This data source is one that is widely used in the field of Urban Economics because of its extensiveness and reliability, and it is therefore unlikely to lead to bias in the estimation of parameters. [9] From these 400, I selected 40 due to the difficulty in plotting the corners, finding their census tracts or wards over a 70-year period and determining which years they were nearby a transit station. The 40 corners were not selected at random, but rather to obtain a mix that were always, sometimes and never near a transit station.

The data corresponding to the racial diversity variable came from the United States' censuses for 1910 through 1970. [14][3] For the years 1910 through 1940, Chicago was separated into wards, and after 1950 it was segmented using census tracts. To find the racial composition for an address, I used the percentage of blacks living in the same ward or tract as the location in question. Although the wards and the tracts changed from year to year, it is unlikely that the malleable shape of the wards and tracts would systematically affect the number of blacks for each of my 40 corners for each of the seven years. Therefore I believe that the racial data are unbiased and reliable.

[3] Additional racial breakdowns by census tract was gathered, specifically for 1950 from <http://trinity.aas.duke.edu/~jvigdor/segregation/>. A few ward maps that were used, particularly the one pertaining to 1940 was obtained from the University of Chicago's Map Library.

Data for the existence of a transit stop were obtained from the Chicago Transit Authority's website that provided system maps for Chicago's elevated rail for the years from 1898 to 2001. [3] The maps show the progression of the "El's" tracks and I assume that their information is unbiased.

I also assume that the year-end closings for the Dow Jones Industrial Average are unbiased and reliable. [2]

Sample statistics for the continuous variables are given in Table 1.

Table 1: Sample Statistics

Variable	Mean	Std Dev	Minimum	Maximum
LV_{it}	7.56	10.34	0.144	81.63
D_i	6.07	2.78	0.599	11.97
$\%Black_{it}$	11.56	27.57	0	99.9
$DJIA_t$	326.41	268.27	99.05	800.36

It is not surprising that the variables have large ranges since they relate to 40 different locations around a city over seven decades. Utilizing the natural log of some of these variables will lower the size of their intervals.[4]

I will check for multicollinearity in three ways. First, I calculated the 231 correlation coefficients between the explanatory variables. Using the rule of thumb that since they are less than .7, this test indicates that multicollinearity will not be a problem in my analysis. The second method highlights possible problematic variables using Variance Inflation Factors (VIF). This test shows that $\ln D_i$ may be correlated with

[4] A consequence of these large intervals is that my observations are unlikely to have large leverage. This idea is supported using normal calculation, $h_i > \frac{2(k)}{n}$ = .4214, which indicates that none of my observations have large leverage.

another variable. Thirdly, I determined the condition indices. The largest condition index is 90.816. Upon further examination of the variance proportion it appears as though there is a severe amount of collinearity between the intercept and the variable $\ln D_i$, a result suggested by the VIF's. Collinearity between $\ln D_i$ and the intercept implies that this explanatory variable remains relatively constant since the computer sets the intercept equal to one for its calculations. This result is not surprising. While the distances in my sample range from about ½ a mile to 12 miles, the natural log of the distances only range from -.693 to 2.485, a much narrower interval. The collinearity between the intercept and the natural log of distance hints at a diminished t-statistic, and therefore the effect of distance on land values is greater than indicated by the regression.

A priori I would not expect autocorrelation to exist. If autocorrelation were a problem, it would indicate that residuals in one year at one location are correlated with the errors a decade later at the same location. It is not likely that the errors in one year are related to those from 20 or more years ago for a specific location. However, one can imagine that between two sample decades, a particular corner gained some new attribute that made its land more valuable. This addition might lead to an understated prediction of land values in my model, as it would not incorporate such new characteristics. However, if the characteristic were added before 1910 and lasted throughout 1970, it would be captured in my model by the location dummy associated with the address in question. Since the chosen locations are from all over the city, while some locations may gain amenities, which increase their value, other locations will suffer new detriments that lower their value. These fluctuations in land value will tend cancel each other out and negate the possibility of autocorrelation. However, I will arrange the data by year, listing each of the 40 corners in the same order so that I may test for autocorrelation of the 40^{th} order, which is equivalent to a decade lag.

Since there is no theory leading me to believe that the residuals are not distributed with a constant variance, my tests for heteroscedasticity will be general in nature. I will test to see if the errors are related to the explanatory variables, their squares or their cross products using the White Test, and I will test for a relationship between the errors and the predicted value of land using both a maximum likelihood test and a version of the Breusch-Pagan-Godfrey test.

4. Empirical Results

Equation (3) is the result of estimating model (2). See results in Table 3.

To determine if equation (3) is the best model for my study, I perform subset F-tests on the variables with year specific effect. I also remove each variable and each year from model (3) one at a time and evaluate the resulting models based on their respective AIC and adjusted R^2. The results appear in Table 2.

Table 2: Hypothesis Tests for Scaling Down Model (3)

			AIC	Adjusted R^2	R^2
Equation (3)			416.893	0.7845	0.8331
		F-Test P-Value	**AIC w/o Variable**	**Adjusted R^2 w/o Variable**	**R^2 w/o Variable**
Variable Examined					
	Distance	H_0: $\lambda_2=...=\lambda_7=0$ H_1: $\lambda_2,...,\lambda_7\neq0$ <.0001	536.396	0.6507	0.72
	%Black	H_0: $\delta_2=...=\delta_7=0$ H_1: $\delta_2,...,\delta_7\neq0$ 0.1131	456.843	0.7766	0.8125
	Transit	H_0: $\tau_1=...=\tau_{36}=0$ H_1: $\tau_1,...,\tau_{36}\neq0$ 0.0005	436.835	0.7625	0.8096
Year Examined					
	1920	H_0: $\lambda_2=\delta_2=\chi_2=0$ H_1: $\lambda_2,\delta_2,\chi_2\neq0$ 0.306	415.458	0.7838	0.83
	1930	H_0: $\lambda_3=\delta_3=\chi_3=0$ H_1: $\lambda_3,\delta_3,\chi_3\neq0$ <.0001	510.816	0.6872	0.7542
	1940	H_0: $\lambda_4=\delta_4=\chi_4=0$ H_1: $\lambda_4,\delta_4,\chi_4\neq0$ <.0001	439.76	0.7625	0.8133
	1950	H_0: $\lambda_5=\delta_5=\chi_5=0$ H_1: $\lambda_5,\delta_5,\chi_5\neq0$ 0.0004	433.081	0.7686	0.8181
	1960	H_0: $\lambda_6=\delta_6=\chi_6=0$ H_1: $\lambda_6,\delta_6,\chi_6\neq0$ <.0001	436.642	0.7654	0.8156
	1970	H_0: $\lambda_7=\delta_7=\chi_7=0$ H_1: $\lambda_7,\delta_7,\chi_7\neq0$ <.0001	467.887	0.7352	0.7918

Based on the above results, the variables that deserve attention are %Black and D1920. Even though I am not able to reject the null hypothesis that the variable %Black affects land value differently over time, when it is removed from model (3), the resulting model's AIC is higher than that of model (3). In addition, the adjusted R^2 is lower than that of model (3). Therefore, I choose to keep the year-specific effects of the variable %Black in my model. I am also unable to reject the null hypothesis that my explanatory variables affect land value differently from one another in 1920. When D1920 is dropped from model (3), the resulting model has a slightly lower AIC, but a lower adjusted R^2 than model (3). I choose not to drop D1920 from model (3) since these results are conflicting and because I believe that the explanatory variables should affect land values differently in 1920 from all of the other years included in my model.

I perform two tests to determine the correct specification of my empirical model. First, I use the White test for model specification. The White Test for model specification yields a p-value of .8820 and therefore I accept the null hypothesis that the model is correctly specified. Second, I check for a systematic relationship between the year specific effects for distance, racial make-up, and transit. To do this, I introduce a single trend variable ranging from 0 (1910) to 6 (1970). I regress land value on the explanatory variables, each of which is now represented by a single variable, as well as variables that are the products of the new trend variable and the independent variables that were shown to have varying effects over time: distance, racial make-up and transit. This results in model (4).

$$\text{(4)} \qquad lnLV_{it} = \psi_0 + \psi_1 lnD_i + \psi_2(tlnD_i) + \psi_3 \frac{1}{\%Black_{it}} + \psi_4(t)\frac{1}{\%Black_{it}}\ \psi_5 T_i +$$

$$\psi_6(tT_i) + \psi_7 lnDJIA_t + \psi_8 C1 + \ldots + \psi_{43} C36 + \varepsilon_i$$

The estimate of model (4) is equation (5). See the Table 3.

Since the AIC and Adjusted R^2 of model (5) are worse than those of model (3), model (3) remains the best model for this study. Model (5) does indicate, however, that only the effect of transit on land value systematically changes over time.

Theory indicates that the only form of autocorrelation that could exist in my study is one that corresponds to a one-decade lag. In order to test for such a form of autocorrelation, I arrange my data so that it is listed by year for each corner and I test for 40^{th} order autocorrelation using the maximum likelihood test for a specific year. The test yielded a p-value for that autocorrelation coefficient of .0069. Therefore, I believe that autocorrelation of the 40^{th} order exists and the superior model is now model (6) (see Table 3), which is model (3) corrected for autocorrelation.

Although theory fails to predict an appropriate form of heteroscedasticity, I use White's heteroscedasticity test of the null hypothesis that the error term variance is constant against the alternative hypothesis that it is not constant. White's test yields a p-value of .8820; therefore I conclude that the error term variance is not a function of the regressors, their squares or cross products at the 5% percent significance level. I also test for a linear relationship between the variance of the residuals and the predicted value of the natural log of land values. The maximum likelihood test for heteroscedasticity gives a p-value of .4784 and Newbold's version of the Breusch-Pagan-Godfrey test generates a p-value of .9013. Since neither test indicates that heteroscedasticity is a problem, model (6) is the preferred empirical model.

The final assumption in the previous section was that the error terms were distributed normally. To check this assumption, tests involving the 3^{rd} and 4^{th} moments of specification of the error term distribution are performed. The D'Agostino and Jarque-Bera tests indicate that the residuals of (6) are not distributed normally. However, I may invoke the Central Limit Theorem to assure that the parameter estimates in my model are close to having a normal distribution, since my sample size is large. Therefore, the non-normality of error distribution will not affect my hypothesis tests.

The Final Empirical Model

My model has a higher coefficient of determination, Adjusted $R^2 = .84$, than those in the previously examined studies. However, the measures of goodness of fit are not truly comparable because the other studies do not use panel data, but are either cross sectional or time series in design

Table 3: Regression Results for the Prediction of Urban Land Value, 1910-1970

	(3) OLS	(5) OLS	(6) OLS
$\ln D_{it}$	-0.920	-0.56	-0.870
	.250*	0.34	0.249*
$D1920\ln D_{it}$	-0.030	-	0.010
	0.079		0.086
$D1930\ln D_{it}$	0.970	-	0.990
	.097*		.099*
$D1940\ln D_{it}$	0.420	-	0.420
	.083*		.089*
$D1950\ln D_{it}$	0.310	-	0.300
	.097*		0.102*
$D1960\ln D_{it}$	0.600	-	0.630
	.148*		.151*
$D1970\ln D_{it}$	0.950	-	1.970
	.156*		.160*
$t\ln D_{it}$	-	0.082	-
		0.023	
$(1/\%Black_{it})$	0.012	-0.007	0.001
	.002*	0.004	0.008
$D1920(1/\%Black_{it})$	-0.007	-	-0.008
	0.003*		0.008
$D1930(1/\%Black_{it})$	-0.012	-	-0.012
	0.003*		0.008
$D1940(1/\%Black_{it})$	-0.011	-	-0.010
	.002*		0.008
$D1950(1/\%Black_{it})$	-0.011	-	-0.011
	.004*		0.009
$D1960(1/\%Black_{it})$	-0.005	-	-0.006
	0.003		0.009
$D1970(1/\%Black_{it})$	0.009	-	0.008
	0.008		0.012
$t(1/\%Black_{it})$	-	-0.001	-
		0.001	
T_{it}	0.186	0.501	0.192
	0.216	0.268	0.221
$D1920T_{it}$	-0.154	-	-0.169
	0.196		0.197
$D1930T_{it}$	-0.212	-	-0.246
	0.203		0.206
$D1940T_{it}$	-0.690	-	-0.736
	.198*		.200*
$D1950T_{it}$	-0.823	-	-0.803
	.205*		.209*
$D1960T_{it}$	-0.531	-	-0.515
	.235*		.233*
$D1970T_{it}$	-0.630	-	-0.599
	0.236		.241*

tT_{it}	-	-0.241	-
		.042*	
$\ln DJIA_t$	-0.380	0.447	-0.382
	.139*	.108*	.139*
C1	-1.000	#	-0.934
	.338*		.345*
C2	-0.409	#	-0.441
	0.265		.273*
C3	-0.199	#	-1.980
	.289*		.297*
C4	-1.660	#	-1.720
	.275*		.275*
C5	-1.360	#	-1.320
	.329*		0.321*
C6	-1.800	#	-1.650
	.269*		.270*
C7	-1.740	#	-1.820
	.266*		.265*
C8	-1.920	#	-2.010
	.278*		.282*
C9	-0.890	#	-0.917
	.275*		.280*
C10	-0.640	#	-0.650
	0.273		.277*
C11	-0.914	#	-0.823
	.226*		.223*
C12	-1.296	#	-0.129
	.253*		.248*
C13	-1.992	#	-1.980
	.294*		.303*
C14	-0.087	#	0.095
	0.639		0.635
C15	-1.000	#	-0.764
	0.465		0.477
C16	0.002	#	0.079
	0.418		0.417
C17	-1.069	#	1.100
	.212*		.210*
C18	-0.711	#	-0.672
	.260*		.265*
C19	-1.940	#	-2.060
	.312*		.324*
C20	-1.870	#	-1.860
	.268*		.277*
C21	-1.210	#	-1.050
	.443*		.434*
C22	-0.834	#	-0.805
	.374*		.350*
C23	-1.490	#	-1.540
	.255*		.257*

C24	-1.920	#	-1.930
	.263*		.268*
C25	-1.850	#	-1.820
	.279*		.266*
C26	0.265	#	0.295
	0.279		0.285
C27	-1.840	#	-1.750
	.293*		.295*
C28	-3.160	#	-3.200
	.277*		.283*
C29	-2.010	#	-1.880
	.256*		.262*
C30	-8.360	#	-0.811
	.301*		.262*
C31	-1.210	#	-1.100
	.248*		.255*
C32	0.296	#	0.304
	0.203		0.210
C33	-0.634	#	-0.697
	.272*		.280*
C34	-1.840	#	-1.790
	.291*		.300*
C35	-0.612	#	-0.546
	.204*		.213*
C36	-0.207	#	-2.160
	.299*		.308*
$e_{(it-10)}$	-	-	0.244
			.089*
Constant	5.450	0.786	5.340
	.906*	0.918	.903*
Adjusted R^2	0.785	0.629	0.840
AIC	416.893	586.534	412.118
Observations	252	252	252

Notes: The dependent variable in each regression is the natural log of land value as described in the text. Regression (3) is the first regression equation before the removal of any explanatory variables was attempted. Regression (5) tests for any systematic relationships between the year specific effects and the explanatory variables of distance, %black and transit. Regression (6) is the final regression model which has been corrected for autocorrelation of the 40th order. A "dash" indicates that a variable was not included in a regression. A "#" signifies that while a variable's coefficient was measured, it was not important enough to merit its inclusion in the table. The numbers beneath the coefficients are standard errors. A * indicates that the coefficient is significant at the 5% level using a 2-sided t-test.

5. Interpretation of the Empirical Results

Distance

Table 4: Distance

Hypothesis Tests

	Test	P-Value	Decision at 5% Level
H_0:	$\lambda_1 \geq 0$	.0007	Reject H_0 in favor of H_1
H_1:	$\lambda_1 < 0$		
H_0:	$\partial LV/\partial D \geq 0$	-	Reject H_0 in favor of H_1 (Implied by λ_1<0)
H_1:	$\partial LV/\partial D < 0$		
H_0:	$\partial^2 LV/\partial D^2 \leq 0$	-	Reject H_0 in favor of H_1 (Implied by λ_1<0)
H_1:	$\partial^2 LV/\partial D^2 > 0$		
H_0:	$\lambda_1 + \lambda_2 = 0$	.0005	Reject H_0 in favor of H_1
H_1:	$\lambda_1 + \lambda_2 \neq 0$		
H_0:	$\lambda_1 + \lambda_3 = 0$	.6059	Accept H_0
H_1:	$\lambda_1 + \lambda_3 \neq 0$		
H_0:	$\lambda_1 + \lambda_4 = 0$	.0679	Accept H_0
H_1:	$\lambda_1 + \lambda_4 \neq 0$		
H_0:	$\lambda_1 + \lambda_5 = 0$	.0195	Reject H_0 in favor of H_1
H_1:	$\lambda_1 + \lambda_5 \neq 0$		
H_0:	$\lambda_1 + \lambda_6 = 0$	.3361	Accept H_0
H_1:	$\lambda_1 + \lambda_6 \neq 0$		
H_0:	$\lambda_1 + \lambda_7 = 0$	.6929	Accept H_0
H_1:	$\lambda_1 + \lambda_7 \neq 0$		

Table 4: Continued

Estimate of Influence

Influence	Estimate
1st Derivative: $\partial LV/\partial D$	-1.08*
2nd Derivative: $\partial^2 LV/\partial D^2$	0.33*
Elasticity in 1910: λ_1	-0.87
Elasticity in 1920: $\lambda_1 + \lambda_2$	-.88
Elasticity in 1930: $\lambda_1 + \lambda_3$	.12
Elasticity in 1940: $\lambda_1 + \lambda_4$	-.45
Elasticity in 1950: $\lambda_1 + \lambda_5$	-.57
Elasticity in 1960: $\lambda_1 + \lambda_6$	-.24
Elasticity in 1970: $\lambda_1 + \lambda_7$	.10

* - calculated at the mean value of distance and land value

Table 4 partially corroborates the theory of the Monocentric model that says that increasing distance from the CBD decreases land values and that this effect diminishes as distance increases. The elasticity of land value with respect to distance negative in all years other than 1930 and 1970, being statistically significant in 1910, 1920 and 1950.

The effect that distance has on land value is almost always less than its effect in 1910. To see if there is a systematic linear change over time, I test the coefficient of the cross product between the trend variable and the distance variable in model (5). The one-sided test shows that this coefficient is not significantly different from zero. Therefore, there does not appear to be a systematic change in the effect of distance on land value over time. This contradicts Atack and Margo's theory, though they never rigorously tested their proposal.

The only variable that seemed to be affected by multicollinearity was the natural log of distance. However, the presence of multicollinearity only strengthens my conclusions about the significant negative effect that distance has on land values.

Racial Make-up

Table 5: Racial Make-up

Hypothesis Tests

	Test	P-Value	Decision at 5% Level
H_0:	$\delta_1 \geq 0$	.1507	Accept H_0
H_1 :	$\delta_1 < 0$		
H_0:	$\partial LV/\partial \%Black \geq 0$	-	Accept H_0 (Implied by accepting $\delta_1 \geq 0$)
H_1 :	$\partial LV/\partial \%Black < 0$		
H_0:	$\partial^2 LV/\partial \%Black^2 \leq 0$	-	Accept H_0 (Implied by accepting $\delta_1 \geq 0$)
H_1 :	$\partial^2 LV/\partial \%Black^2 > 0$		
H_0:	$\delta_1 + \delta_2 = 0$	.1371	Accept H_0
H_1 :	$\delta_1 + \delta_2 \neq 0$		
H_0:	$\delta_1 + \delta_3 = 0$	.7714	Accept H_0
H_1 :	$\delta_1 + \delta_3 \neq 0$		
H_0:	$\delta_1 + \delta_4 = 0$	.2216	Accept H_0
H_1 :	$\delta_1 + \delta_4 \neq 0$		
H_0:	$\delta_1 + \delta_5 = 0$	.8516	Accept H_0
H_1 :	$\delta_1 + \delta_5 \neq 0$		
H_0:	$\delta_1 + \delta_6 = 0$	.0809	Accept H_0
H_1 :	$\delta_1 + \delta_6 \neq 0$		
H_0:	$\delta_1 + \delta_7 = 0$	.0177	Reject H_0 in favor of H_1
H_1 :	$\delta_1 + \delta_7 \neq 0$		

Table 5: continued

Estimate of Influence

Influence	Estimate
1st Derivative: $\partial LV / \partial \%Black$	-.001*
2nd Derivative: $\partial^2 LV / \partial \%Black^2$	.001*
Elasticity in 1910: $\frac{-\delta_1}{\%Black}*100$	-.1*
Elasticity in 1920: $\frac{(\delta_2 - \delta_1)}{\%Black}*100$	-.17 *
Elasticity in 1930: $\frac{(\delta_3 - \delta_1)}{\%Black}*100$	-.21*
Elasticity in 1940: $\frac{(\delta_4 - \delta_1)}{\%Black}*100$	-.19*
Elasticity in 1950: $\frac{(\delta_5 - \delta_1)}{\%Black}*100$	-.12*
Elasticity in 1960: $\frac{(\delta_6 - \delta_1)}{\%Black}*100$	.16*
Elasticity in 1970: $\frac{(\delta_7 - \delta_1)}{\%Black}*100$	-.03*

* - calculated at the mean value of distance and land value

The results from model (6) and in Table 5 do not support the theory that as the black population in a neighborhood grows, the land values in that area decrease. This result is surprising and contradicts Kern's article. Model (5) tests to see whether the effect of the percentage of blacks living in an area have on land value systematically changes over time. The systematic linear effect is statistically insignificant.

The yearly elasticites of land value with respect to the percentage black in an area are negative, except in 1970, but minute.

Transit

Table 6: Transit

Hypothesis Tests

	Test	P-Value	Decision at 5% Level
H_0:	$\chi_1 \leq 0$	0.3857	Accept H_0
H_1:	$\chi_1 > 0$		
H_0:	$(e^{\chi_1} - 1)*100 \leq 0$	-	Accept H_0 (Implied by $\chi_1 \leq 0$)
H_1:	$(e^{\chi_1} - 1)*100 > 0$		
H_0:	$\chi_1 + \chi_2 = 0$	.9172	Accept H_0
H_1:	$\chi_1 + \chi_2 \neq 0$		
H_0:	$\chi_1 + \chi_3 = 0$	.8079	Accept H_0
H_1:	$\chi_1 + \chi_3 \neq 0$		
H_0:	$\chi_1 + \chi_4 = 0$	.0132	Reject H_0 in favor of H_1
H_1:	$\chi_1 + \chi_4 \neq 0$		
H_0:	$\chi_1 + \chi_5 = 0$	.0033	Reject H_0 in favor of H_1
H_1:	$\chi_1 + \chi_5 \neq 0$		
H_0:	$\chi_1 + \chi_6 = 0$	.1730	Accept H_0
H_1:	$\chi_1 + \chi_6 \neq 0$		
H_0:	$\chi_1 + \chi_7 = 0$	.0563	Accept H_0
H_1:	$\chi_1 + \chi_7 \neq 0$		

Estimate of Influence

Influence	Estimate
Semielasticity in 1910: $(e^{\chi_1} - 1)*100$	20.44
Semielasticity in 1920: $(e^{\chi_1+\chi_2} - 1)*100$	1.71
Semielasticity in 1930: $(e^{\chi_1+\chi_3} - 1)*100$	-5.82
Semielasticity in 1940: $(e^{\chi_1+\chi_4} - 1)*100$	-42.31
Semielasticity in 1950: $(e^{\chi_1+\chi_5} - 1)*100$	-46.04
Semielasticity in 1960: $(e^{\chi_1+\chi_6} - 1)*100$	-28.04
Semielasticity in 1970: $(e^{\chi_1+\chi_7} - 1)*100$	-33.83

The surprising results in Table 6 contradict the idea that the presence of a transit stop increases land values, since in the post-1920 years the effect of transit on land value is negative, though insignificant. Also, the semielasticity of land value with respect to the existence of a transit stop is negative in the post-1920 years.

This conclusion may highlight one limitation of my model. The transit variable is not continuous and so denies the possibility of a diminishing marginal influence of distance from the transit stop, the less appealing it is a form of transportation. Furthermore, this model assumes that transit is only a viable option for travel if one lives within 1/3 from an "El" station. In fact, many people may be willing to walk farther than 1/3 of a mile to ride the "El."

For the post-1910 test years, the effect that a transit stop's presence has on land value is lower than the effect in 1910, becoming negative after 1920. To see if there is a systematic linear change over time, I test to see if the coefficient of the cross product between the trend variable and the transit dummy in model (5) is negative. The test shows that this coefficient is significantly different from zero and negative. Therefore, I conclude that the effect of transit stations on land value has become increasingly negative over time.

Dow Jones Industrial Average

Table 7: Dow Jones Industrial Average

Hypothesis Tests

	Test	P-Value	Decision at 5% Level
H_0:	$\alpha_1 \leq 0$	.9968	Accept H_0
H_1 :	$\alpha_1 > 0$		
H_0:	$\alpha_1 \geq 1$	-	Reject H_0 in favor of H_1 (Implied by $\alpha_1 \leq 0$)
H_1 :	$\alpha_1 < 1$		
H_0:	$\partial LV / \partial DJIA \leq 0$	-	Accept H_0 (Implied by $\alpha_1 \leq 0$)
H_1 :	$\partial LV / \partial DJIA > 0$		
H_0:	$\partial^2 LV / \partial DJIA^2 \geq 0$	-	Accept H_0 (Implied by $\alpha_1 \leq 0$)
H_1 :	$\partial^2 LV / \partial DJIA^2 < 0$		

Estimate of Influence

Influence	Estimate
Elasticity: α_1	-.382
1st Derivative: $\partial LV / \partial DJIA$	-.0091*
2nd Derivative: $\partial^2 LV / \partial DJIA^2$	.00004*

* - calculated at the mean value of DJIA and land value

The results in Table 7 contradict the theory proposed at the beginning of the paper since they indicate that the effect of a rising DJIA on land values is not positive. Furthermore the effect does not diminish as the DJIA increases. This may indicate that common stocks are investment substitutes for real estate, and that speculative bubbles might exist. However, the explanation may be simpler in that perhaps my measurement of wealth is inappropriate.

Corner Dummy Variables

Table 8: Hypothesis Tests for the Corner Dummy Variables

Hypothesis Tests

	Test	P-Value	Decision at 5% Level
H_0:	$\tau_i = 0$	-	Reject H_0 for 1,2,3,4,5,6,7,8,9,10,11,12,13,17,18,19,20, 21,22,23,24,25,27,28,29,30,31,33,34,35,36
H_1 :	$\tau_i \neq 0$		
H_0:	West = 0	<.0001	Reject H_0 in favor of H_1
H_1 :	West $\neq$ 0		
H_0:	South = 0	<.0001	Reject H_0 in favor of H_1
H_1 :	South $\neq$ 0		

Estimate of Influence

Influence	Estimate
Average of Coefficients of Western Corners	-1.055
Average of Coefficients of Southern Corners	-1.605
Net Semielasticity of Western Corners	-65.18
Net Semielasticity of Southern Corners	-79.91

The results in Table 8 indicate that 31 out of the 36 corner dummies are significant.[5] Chicago is a large and diverse city and was so for most of 20th century. Therefore it is not surprising that my sample contains locations that contain unique

[5] There is no obvious relationship between the five corners that are insignificant. Three were "north" of the city and two were "east" of the city. Four were always "near" a transit station, one was sometimes "near" a station. Finally, their distances from the CBD varied greatly, ranging from 1.2 miles to 7.3 miles away from State and Madison.

characteristics that affect the value of land around them over the 60-year period examined in a way that is statistically different from other locations.

The next two tests indicate that the corners that fit my definitions of west, (between the Kennedy Expressway and the Chicago Sanitary and Ship Canal) and south, (south the Kennedy Expressway) have an effect on land value that is statistically different than that of the corners that are north of the city. On average, being west of the city appears to have a negative effect on land values. Being south of the city has a similar effect, though larger. This contradicts Mills' theory since he believed that the direction to the CBD was not an important determinate of a location's land value.[6]

6. Summary and Conclusions

The conclusions of my study of urban land values during the 20th century are startling. The main proposition of the Monocentric model is that land values and distance are inversely related. My model indicates that this is the case in only two of the seven decades tested. Moreover, my results contradict the previously held notion that the effect of distance on land value diminishes over time. My model also conflicts with the hypothesis that racial prejudice leads to diminished land values, since the effect of an increasingly black population on land value was slightly positive and never significant

[6] 12 out of 280 observations are outliers and 15 are influential. Both of these sets of observations appear to be random, that is, there is no obvious pattern according to year, corner, or direction. To see if these observations affect my conclusions, I removed them from my data set. After re-running all of my regressions using this new "purified" data set, none of my conclusions about significance or direction of influence change.

over the 60-year period. Another surprising result of my model is that the addition of a viable option for transit does not appear to have a positive effect on land values. Moreover, the negative effect of the presence of a transit of stop on land values becomes increasingly pronounced over time. The wealth of the economy does not appear to have a positive effect on land values either. Finally, my model shows the direction from the CBD is a significant determinant of land value in direct opposition to Mills' theory.

Why does my model fail to support so much of the common wisdom about the determinants of land values? It is possible that my measurements for the above explanatory variables are inappropriate. Distance could be measured along actual routes to the CBD, rather than the straight-line distance to the CBD. The percentage of blacks living in an area could be determined from some source other than ward maps and census tracts. Transit could be included as a continuous variable instead of as a dummy variable by including an explanatory variable that measured distance to a transit station. Wealth could be measured by something other than the DJIA. However, a more likely justification for the surprising results of my model involves the 36 location-specific variables.

None of the literature that I reviewed captures the unique attributes of a location that affect its land value and are constant over time. By failing to include these effects, previous models have incorrectly determined the effects of distance, prejudice and transit on land value.

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