How Does Light Rail Transit Affect Urban Land Use?

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This paper estimates the effect of the Hiawatha Light Rail Transit (LRT) line on land use change in Minneapolis, MN, between 2000 and 2010. I use a binomial logit model and find that within the 1-mile submarket near LRT, the effect of distance to LRT stations on land use change had a different radius and magnitude depending on existing land use. The effect of LRT on conversions of low-density housing to denser uses only extended out to 90 feet from stations after LRT went into operation. Vacant and industrial land were the most likely to experience land use change, especially in working class, mixed land use neighborhoods with higher population densities. In general, the effect of LRT on land use change was limited in high income neighborhoods. Zoning policy changes around stations had a small but significant positive effect on land use change.

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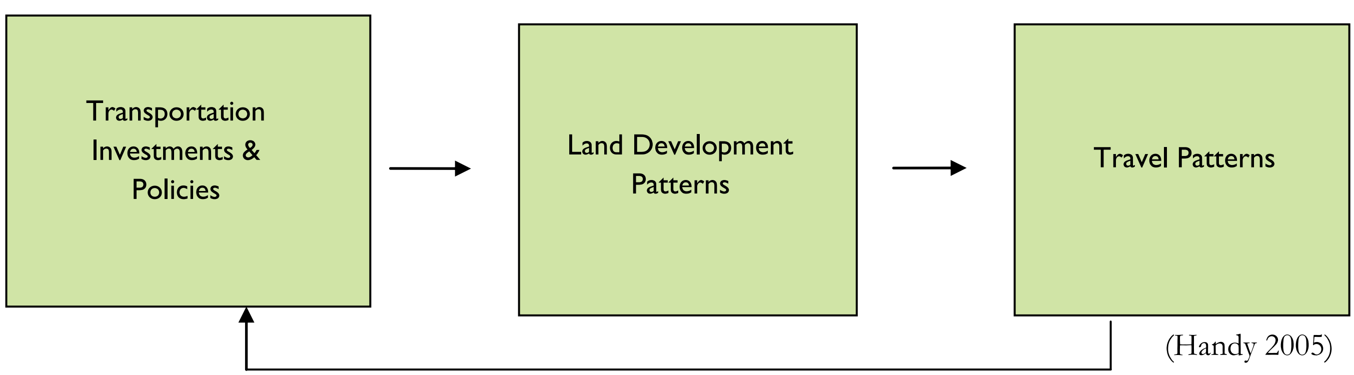
1. Introduction

Economists and geographers have discussed the connection between transportation and land use for more than a century. The historic evolution of urban form, from dense, monocentric cities to suburban sprawl, follows innovations in transportation technology, particularly the personal automobile (Muller 2004). Over the last sixty years, low-density, automobile-oriented sprawl has become the dominant metropolitan growth pattern. From 1970 to 2000, the population of U.S. metropolitan areas increased by 62%, while the percentage of the population living in the central city decreased by 8% (Handy 2005). Transportation infrastructure investment has driven this urban population decrease. Recent estimates suggest that one new highway passing through the central city reduced that city's population by 18% between 1950 and 1990 (Baum-Snow 2007).

The evolution of sprawl is an example of how car-oriented infrastructure investments created low-density land development patterns. Development patterns reinforce travel patterns, and in the case of sprawl, car-oriented travel patterns create negative environmental externalities. This causal system is known broadly as the transportation-land use connection.

Figure 1: The Transportation-Land Use Connection



(Handy 2005)

In response to the community and environmental externalities of sprawl, policymakers are adopting "Smart Growth" policies designed to increase urban density and reduce car-dependency.

These policies promote walkable communities, local employment generation and urban infill. Transportation improvements, especially light rail transit (LRT), are seen as tools that divert automobile riders to mass transit—decreasing pollution and congestion while achieving higher urban land use density (APA 2002).

City planners expect LRT investments will induce land use change, but transportation-land use theory predicts ambiguous results depending on the extent of the existing transit network. US cities have extensive, cheap transit options already. Roads are pervasive, well-maintained and accessible without much cost beyond initial purchase of an automobile. In cities with excellent roads where people can easily obtain cars, LRT investment may not change the relative accessibility of a location enough to incentivize residents and businesses to move to areas with LRT. If there is no change in land demand near stations, land use change and dense development patterns will not occur without more government intervention (Guiliano, 1995).

Once pre-existing transportation conditions are factored in, the theory is not definitive about LRT's potential to induce land use change. In order to determine if there is an effect, we need to continue to build empirical evidence that examines whether and how LRT investment, complementary policies and pre-existing conditions create land use change.

This paper analyzes the effects of the Minneapolis Hiawatha Line (opened in 2004) on land use change from 2000 to 2010, evaluating whether or not land use change occurred and why. There remain large gaps in this literature between previous studies and new modeling techniques and theory. The developer decision theory has been tested using a binomial and multinomial logit model to describe the conversion of agricultural land to residential homes on the urban fringe, but has not been used in the urban transportation-land use context (Bockstael 1996; Chakir and Parent 2009). Previous studies of light rail's effects do not have access to property-level information over their period of analysis, limiting their ability to disaggregate findings by use type and property characteristics. This study uses property-level data in a binomial logit model to test whether transit improvements alter the urban landscape. When applied to the urban setting, the land developer decision model allows us to parse out decision calculus of land developers, shedding new light on supply-side interactions with urban light rail. In particular, we can understand which types of land use conversions are most profitable with respect to distance from LRT stations. This study focuses on the Hiawatha Line in Minneapolis, Minnesota, and land use change occurring from 2000 to 2010.

The paper is divided into eight sections. Section 2 explores the theoretical implications of LRT investment from the perspective of the Alonso-Muth-Mills location model and explores newer, agent-based theoretical approaches; Section 3 reviews the key studies in the transportation-land use field; Section 4 provides an introduction to the data; Section 5 gives a geographic introduction to the Hiawatha line and summarizes land use change in the study area; Section 6 presents the estimation results; Section 7 discusses potential problems with endogeneity and omitted variable bias; and Section 8 concludes.

2. Theory

Understanding theory can help evaluate the potential land market reactions to government transportation interventions like light rail transit. In this section, I will use a simple extension of the Alonso-Muth-Mills model that includes transportation options to predict changes in housing prices, then turn to more recent landowner decision models (e.g. Bockstael 1996) to relate price changes to land use change.

2.1 Location Theory and Housing Prices

The most basic spatial equilibrium model—the Alonso-Muth-Mills (AMM) model—allows us to see changes in a representative city's spatial equilibrium after investment in public transit. Specifically, the AMM model explores the how the price of housing, preferences for quantity of housing, land prices, building height, and population density differ at various distances from the central business district (CBD). The model was developed William Alonso (1964) and later extended upon by Richard Muth (1969) and Edwin Mills (1972). The general findings of the model emerge from a key insight that commuting cost differences within the city must be balanced by differences in the price of living space (Brueckner 1987). This property leads to several other properties necessary to achieve spatial equilibrium in a monocentric city (Kraus 2003):

1. The price of housing is a decreasing function of distance to CBD.
2. Individuals who live farther from the CBD consume more housing.
3. The rental price of land decreases as distance from CBD increases.
4. Structure density decreases as distance from CBD increases.
5. Population density decreases as distance from the CBD increases.

Expansions of the model that include transportation modes (public transit vs. car) as a function of distance from the CBD provide some interesting general relationships:

1. Residents purchase cars when the time-money cost of using public transit is greater than the fixed cost and variable costs of using an automobile.
2. LRT investments provide the incentives for residents to move near stations based on savings in transportation costs.

3. The increase in demand for housing near LRT causes housing prices to increase until the price per square foot exactly matches the savings from lower transportation costs.

The basics of the AMM model are well known (see Bruekner 1987 or Glaeser 2008 for more in-depth review). Table 2.1 outlines the general model. The key equation states that the marginal change in the price of housing for each distance *x* from the CBD must equal the marginal change in transportation costs per unit of housing:

2.1 $\frac{\partial p}{\partial x} = -\frac{\frac{\partial t}{\partial x}}{q}$

Table 2.1: Alonso-Muth-Mills' Model Basic Components

Actors	Working city inhabitants
They Maximize	$\underset{choose\ x}{Max} = U(q,c) - \lambda[W - t(x) - pq - c]$
They Choose	Working inhabitants choose a distance from their house to the CBD that maximizes utility.
Key Equilibrium Equations	$\frac{\partial p}{\partial x} = -\frac{\frac{\partial t}{\partial x}}{q}$ $p(x) = p(\bar{x}) + \frac{t(x)}{q}\left(\sqrt{\frac{Nql}{\pi}} - x\right)$
Notation	
U(q, c)	Individual's utility function
c	Consumption = W-t(x)-r(x)H
q	Housing services
N	Population
W	Wage
x	Distance from the CBD
t(x)	Commuting costs
p(x)	Price of housing gradient
p-bar	Rent at the city edge (p(x-bar))
N*q*l	Total amount of land *l* covered by housing for population N

Adapted from Table 2.1 Glaeser (2008)

The other key equation specifies the price of housing at distance x is the price of housing at the city edge plus the savings in transportation cost per square foot if a resident moves closer to the CBD. The formula for the price of housing at location x is where $\sqrt{\frac{Nql}{\pi}}$ is the radius of the city:

2.2 $$p(x) = p(\bar{x}) + \frac{t(x)}{q}\left(\sqrt{\frac{Nql}{\pi}} - x\right)$$

A simple extension of the model allows residents to choose the cost minimizing transportation technology at each distance from the CBD. In this extension, the price of housing still decreases over distance exactly proportional to the increase in transportation costs per unit of housing: $\frac{\partial p}{\partial x} = -\frac{\frac{\partial t}{\partial x}}{q}$.

Let's assume that there are two transit technologies available to residents: one with fixed capital cost but low variable costs and one with high variable costs but no fixed cost. Typically, the first technology represents automobile transit; the second technology represents public transit. In general, I assume the variable cost of public transit is greater than the variable cost of automobile transit: $v > z$. Mathematically these two options are:

2.3 $$t(x) = \begin{matrix} z(x,N) + F \\ or \\ v(x,N) \end{matrix}$$

Variable costs depend on distance traveled x and congestion from the number of people using the same technology N (congestion effect) in both cases. Residents minimize commuting costs $t(x)$ and will therefore choose to invest the fixed cost into an automobile only when $v(x,N) > z(x,N) + F$. Thus, after a certain distance from the CBD, residents will start using the fixed cost technology because it minimizes $t(x)$. Figure 2.1 illustrates:

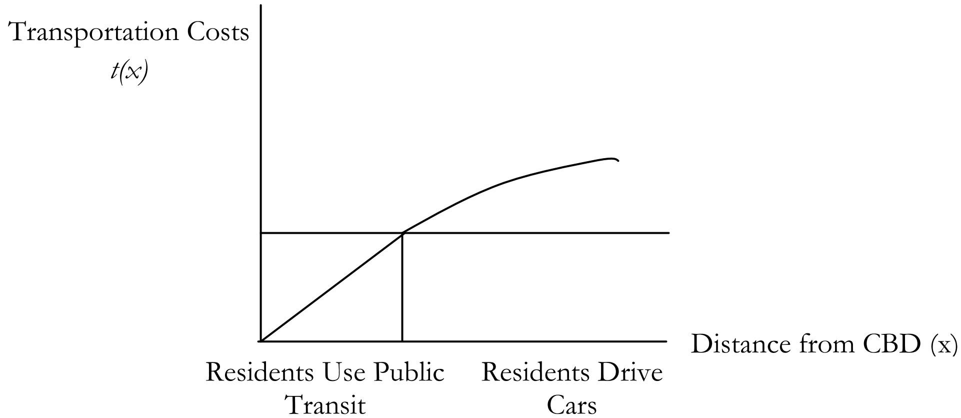


Figure 2.1: When the cost of public transit is more than the cost of car transit, residents will purchase cars.

Recalling Equation 2.3, we know the price of housing at any point in the city is the price of housing at the edge plus the transit cost per unit of housing at some distance from the edge. To update the price function with the new transit choice component, we can say:

2.4 $$p(x) = \begin{cases} p(\bar{x}) + \frac{v(x,N)}{q}\left(\sqrt{\frac{Nql}{\pi}} - x\right) & if \quad v(x,N) < z(x,N) + F \\ p(\bar{x}) + \frac{F+z(x,N)}{q}\left(\sqrt{\frac{Nql}{\pi}} - x\right) & if \quad v(x,N) > z(x,N) + F \end{cases}$$

For the first equation, the cost gradient is typically modeled as linear, while the second equation is convex (Glaeser 2008). Because $\frac{\partial p}{\partial x} = -\frac{\frac{\partial t}{\partial x}}{q}$ and $\frac{\partial v}{\partial x} > \frac{\partial z}{\partial x}$, the area of the city where public transit is cheaper will have a steeper price gradient than the area where automobile transit is cheaper. Figure 2.2 and 2.3 graphically explore how these changes affect the household decision model:

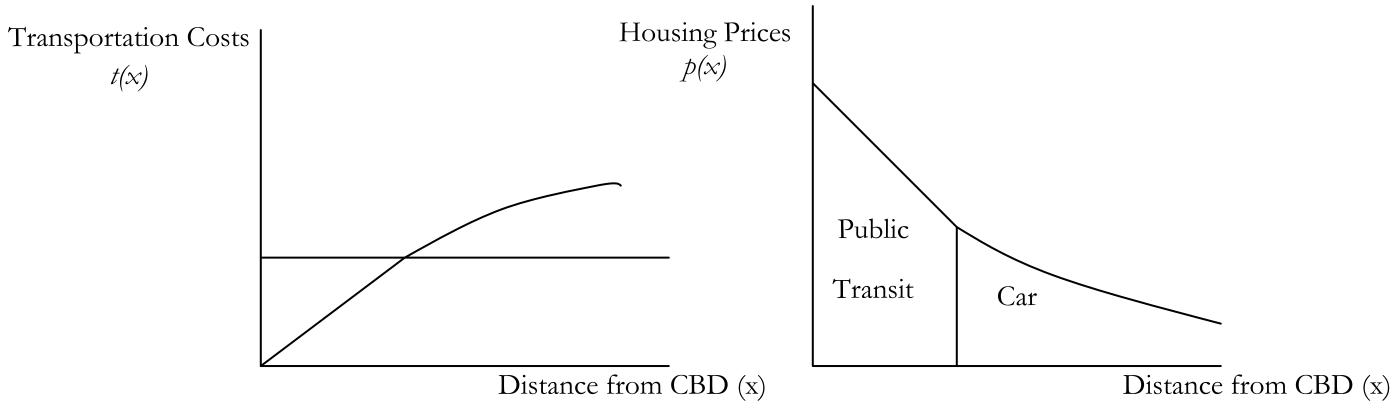


Figure 2.2 & 2.3: Following equation 2.1, the slope of the variable cost of transportation corresponds to the negative slope of the housing price gradient.

As I determined above, residents will minimize transportation costs by choosing between two types of transportation: automobiles and public transit. In both cases, the variable costs depend on the distance traveled and the number of people who use that transit technology. Spatially, Figure 2.4 shows there is a clear point ($v(x,N) > z(x,N) + F$) where the variable cost of public transit is greater than the fixed cost and variable cost of automobiles. Furthermore, I define the city size to where the price of land for housing is less than the price of land for agriculture:

(2.5) $p(\bar{x}) + \frac{F+z(x,N)}{q}\left(\sqrt{\frac{Nql}{\pi}} - x\right) < p_a$:

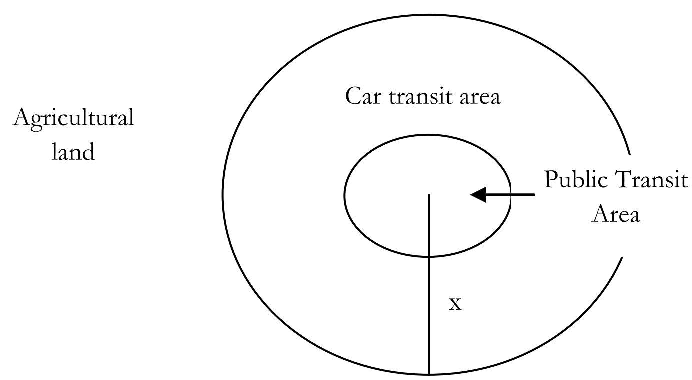


Figure 2.4: City size is limited to where the price of housing is higher than the price of using that land for agriculture. Therefore, the city edge is based on transportation modes and relative costs.

Suppose the city government installs a LRT line in one area of the city from the CBD to point x_b. The transportation cost line pivots down as the variable cost of transit decreases in the area served by the LRT. The distance between the old cost line and the new cost line is transportation cost savings for residents living between the CBD and x_b. Figure 2.5 shows this effect on transportation costs for two different areas within the city—the area with the LRT and the area without the LRT. These effects, in turn, change the rent gradient (following equation 2.1) and city size (shown in Figure 2.6).

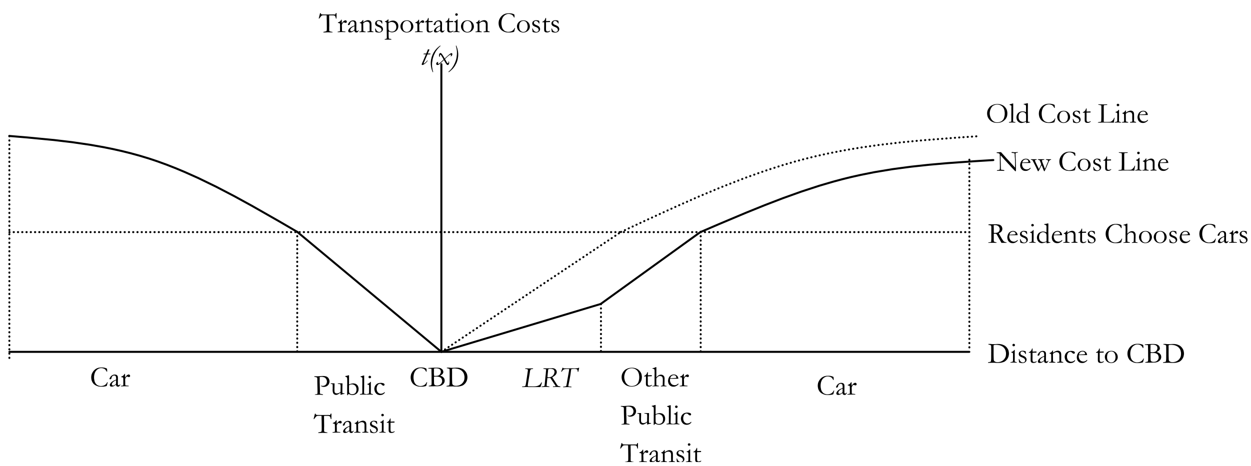


Figure 2.5 Transportation Cost Changes for LRT: After LRT is installed, the entire cost curve changes due to the network effect of transit investment.

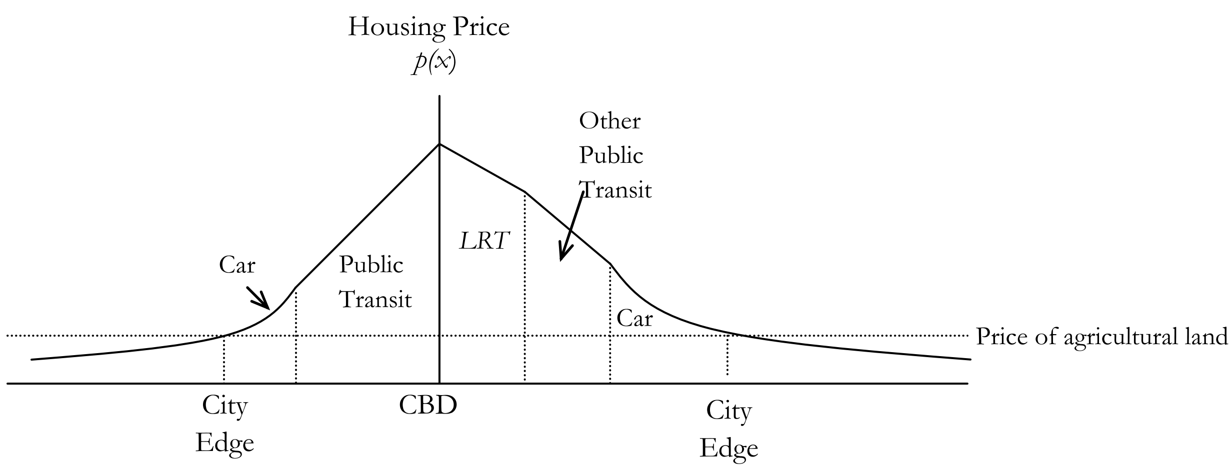


Figure 2.6 Housing Price Changes: After LRT is installed, the price gradient in the area with LRT shifts up. Prices are higher farther out, meaning the city will expand until the price of housing equals the price of land for agriculture.

LRT investment increases the area where public transit is a viable alternative to driving. This increase, however, can lead to more sprawl because of induced demand. The distance at which buying a car is worthwhile is pushed outward, so car users are able to live farther from the CBD than before. Transportation becomes cheaper; if more people use LRT, then fewer people will use cars, decreasing the congestion on roads. Decongested roads make transit costs for car drivers lower, thus increasing the distance a car driver is willing to live from the CBD (an effect not shown above). The increase in housing prices from of LRT cause city size to expand; the price of housing is now higher than the price of using land for agricultural purposes at the city edge.

The change in housing prices will be equal to the old transportation cost minus the new transportation costs. The network effect of the transportation improvement may alter the transportation costs in areas without LRT.

(2.6)

$$\Delta P_{housing} = \begin{cases} v(x,N) - LRT(x,N) & \text{for area with LRT} \\ v(x,N) - v(x^{*},N^{*}) & \text{for area without LRT served by public transit} \\ [F + v(x,N)] - [F + v(x^{*},N^{*}) & \text{for area without LRT served by automobile transit} \end{cases}$$

But is the change in transit cost large enough to cause residents to move? If car ownership is pervasive, even among people living near downtown, then the LRT may not change the cost of transportation at all for the majority of residents. Only those residents who live within a tight radius of the stations would experience a decrease in the cost of transportation. The theory predicts land use changes will only occur if the marginal decrease in transportation costs is large. Given the transaction costs associated with relocating, the decrease must be even greater to truly induce residents to move to LRT-accessible areas.

There is another reason people might demand to live near LRT that is not modeled above. If a large group of individuals prefer to live near LRT and have a high willingness to pay for transit-accessible housing, then prices may go up. Instead of maximizing utility by choosing distance from the CBD, these individuals maximize utility by choosing a transit option. People who prefer the ease of LRT—college students, the elderly, people with disabilities, etc.—will be predisposed in favor of high-density living near stations.

2.2 Agent-Based Approach and Land Use Change

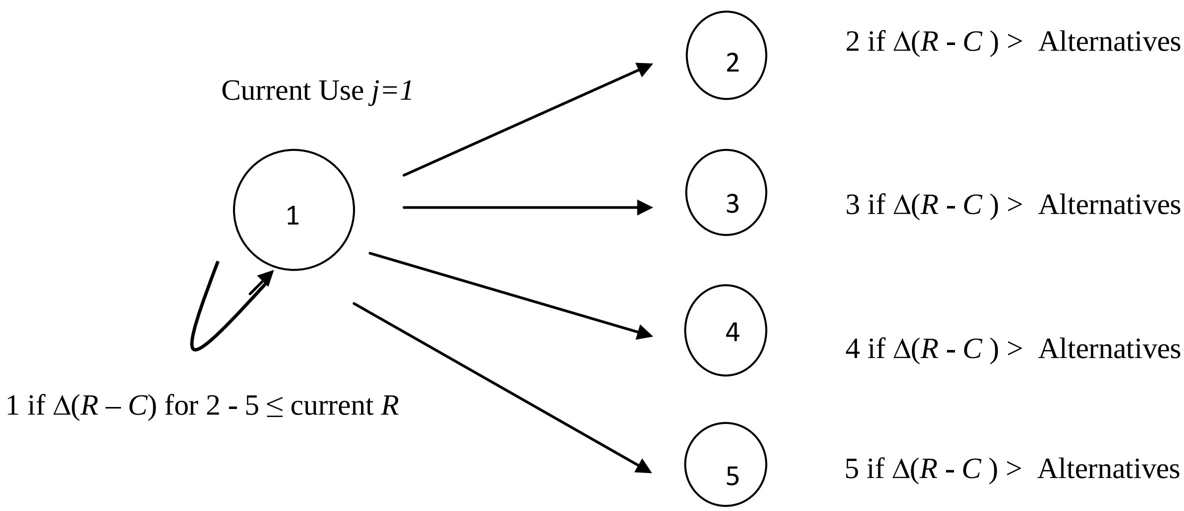
A complementary model of land use change builds on the Alonso-Muth-Mills theory in section 2.1. The model explicitly examines how price changes predicted in AMM translate into incentives for landowners. For this section, I draw on the land conversion theory developed by Bockstael (1996) to examine land use change on the urban-rural fringe and the multinomial discrete choice model refined by Chakir and Parent (2009). Using land conversion theory in conjunction with location theory, I analyze the effects of light rail transit from the perspective of the land developer.

The fundamental agent of land use change in the model is the land developer or land owner. The theoretical geographic area is composed of heterogeneous land uses that fall into five categories: vacant, low density housing, high density housing, industrial, and commercial. To keep clear the reaction of developers to the expected value of properties in the model, I also assume developers are perfectly competitive and risk neutral.

Each property i begins at time t in a current land use j ($j \in J$, J = set of five possible uses) and has a future land use k ($k \in J$) in time t+1. The developer decides to change from one land use to another land use if the present discounted value of the expected difference in future revenue streams minus conversion costs is greater than the revenue streams of the current use or any alternative use's discounted net revenue stream. For example, a developer will convert a property from single-family home to multi-family home if the expected net increase in profits is more than profits from the current land use or converting to commercial, industrial, or undeveloped.[1] Figure 2.7 visually represents how Revenues and Costs (*R* and *C*) affect the decision.

Figure 2.7 Decision to Convert

Potential Future Uses *k=1,2,3,4,5*



In this theoretical model, light rail transit has heterogeneous positive and negative effects on different uses as distance from LRT varies. Residential properties directly adjacent to the station area may interpret LRT as a noise and privacy disamenity while retail businesses may highly value the same location. Whether or not land use change occurs indicates how LRT proximity is capitalized into developers' expected net profit and the magnitude of the capitalization effect, defined in this model by equation 2.6. Which land use has a higher probability of conversion near LRT is a function of the profit-maximizing decisions of developers.

Consider revenue from properties. In equations 2.7 and 2.8, R_{ijt} and R_{ikt} are the expected present discounted value of the sum of future income streams from two potential land use choices *j* and *k*, and *r* is the discount rate. v_{ijt} and v_{ikt} are the expected annual streams of income. The time

[1] Profits can be explicitly gained from renting to others or implicitly gained from the value of services derived from living in the location themselves.

period where the property generates income is *T*. Again, income may be a function of rent or may be implicit value derived from the agent living there himself.

(2.7) $R_{ijt} = E\left[\sum_{t=1}^{T} \frac{v_{ijt}}{(1+r)^t}\right]$

(2.8) $R_{ikt} = E\left[\sum_{t=1}^{T} \frac{v_{ikt}}{(1+r)^t}\right]$

The change in profit from conversion is:

(2.9) $z_{ikt} = (R_{ikt} - R_{ijt}) - C_{ikt}$

In equation 2.9, z_{ikt} is the expected profits from the conversion of property *i* from *j* to *k* in time *t*. C_{ikt} is the cost of converting from land use *j* to land use *k* in time *t*.

Using these components, I can model the decision of a developer to convert a property. A developer will choose to convert a property to use k^* if k^* maximizes the change in profit z_{ikt}.

(2.10) $L_{it+1} = k^*, \text{if } (z_{ik^*t} > z_{ikt}) \quad \forall\, k$

L_{it+1} is the land use of property i at time $t+1$. This model specifies not only the type of land use conversion but also the timing of the decision. The decision to convert to a specific future use is dependent on whether or not that future use maximizes the increase in profit compared to the current use and other alternatives. In the empirical model, I test whether developers value light rail transit improvements differently across land uses.

From the perspective of the researcher, there are unobservable variables affecting change in profit z_{ikt}. Therefore, I rewrite z_{ikt} to specify a systematic portion s_{ikt} (observable contributors to profit) and stochastic portion e_{ikt}. The decision equation therefore becomes:

(2.11) $Prob_{ik^*t+1} = Prob(s_{ik^*t} + e_{ik^*t}) > s_{ikt} + e_{ikt}$

The probability of parcel *i* having land use k^* in time t+1 is the probability that the expected increase in profits is greater than the increase in profits from any other future use *k*.

The Alonso-Muth-Mills extension and the agent-based land use change model show that LRT investments decrease transportation costs, which increases demand for housing near stations, pushing housing prices up. The price change from equation 2.6 provides incentives to existing landowners and developers to convert properties to new uses—increasing urban density and providing more housing. The extent of the land use change hinges on how LRT affects transportation costs. Very limited land use changes or changes that are concentrated in a small radius around stations would support the proposition LRT does not change marginal transportation costs enough to induce land use change.

3. Transportation – Land Use Literature

Empirical research on the transportation-land use connection is needed to evaluate the extent of the effects predicted by the theory. The first modern transit system-land use study analyzed the effects of San Francisco's BART commuter rail system. Knight and Trygg (1977) use summary statistics and interviews to conclude that "beneficial" land use changes due to the Bay Area Rail Transit (BART) system were contingent on a growing local economy, supportive zoning and development policies, and public sector involvement. Subsequent studies on San Francisco's BART (Cervero and Landis 1997), Atlanta's MARTA (Bollinger and Ihlanfeldt 1997), Washington, D.C.'s METRO (Cervero 1994), and several California rail systems (Landis et al. 1995) debate these pre-conditions with greater specificity.

An extensive 1997 literature review summarizes the development of the empirical literature after Knight and Trygg's initial analysis (Vessali 1997). We learn from this meta-review that the impacts of light rail transit on land use are typically limited to a very small area near stations. Table 3.1 replicates the excellent summary of 38 pre-1997 studies by Vessali. In the context of the theoretical debate, these empirical results support the argument that the marginal increase in transit accessibility alone is not large enough to alter broad land use patterns without government assistance.[2]

Methodological and theoretical advances have informed the debate over the last 15 years. I classify the set of newer studies (1997 – 2010) as hedonic models, which examine property values, or density models, which examine changes in land use, population, and employment density. Hedonic studies provide information about whether LRT investment changes nearby property values—the first step necessary to induce land use change. Density studies evaluate directly whether land use, employment and population changes occur. If changes do occur, these studies can show what

[2] For more details on this perspective, see Giuliano, 1995 and Cervero and Landis, 1995.

combination of complementary policies, pre-existing conditions, and LRT investment strategies most directly affects land use.

Table 3.1: Vessali's Summary of Empirical Findings (38 Studies)
1. Land use impacts of transit are observed, but they tend to be small for heavy rail systems and even smaller for light rail systems.
2. There is mixed evidence that the impacts are smaller in high-income areas.
3. Access to transit has an average price premium of six to seven percent for single-family homes.
4. Transit access has a mixed and inconsistent effect on commercial property values.
5. For systems that run from the central city to the city edge, areas near the city edge experience the greatest land use impacts because there is more room for development.
6. Transit-oriented development tends to transfer development from other areas of the metro area, rather than create new growth for the region.
7. Around transit stations, commercial uses tend to replace residential and industrial uses over time, but residential growth is very noticeable along the transit corridor.
8. A few studies that compared transit effects on residential vs. commercial properties find mixed results as to which type experience more profound effects.
9. Almost exclusively, transit systems' impacts on land use are limited to rapidly growing regions with healthy underlying demand for high-density development.
10. Public sector involvement (i.e. zoning, land assembly, restrictions on parking, TOD incentives) is common enough to be considered necessary. Some even claim that transit investment may drive policy changes that affect land use more than the transit itself.

(Summary of Empirical Findings p. 95, Vessali 1997)

Recent hedonic models address the heterogeneous effects of LRT on prices in various areas of the city, testing whether certain areas experience property value gains from LRT while other areas do not. Several authors segment the housing market by station areas or by general neighborhood in order to parse out the price effect on different geographies (Goetz et al 2010; Hess & Almeida 2007). Another more complicated approach is to use a geographically-weighted regression to isolate the effect of LRT on each property—estimating different effects across the full universe of property observations (Du & Mulley 2006). The evidence from these studies consistently suggests that allowing for geographic variation in the price effect improves the hedonic model's accuracy. The price increase fueled by residential housing demand does indeed differ across the entire city. This evidence supports the empirical findings that land use change occurs only in certain areas along the transit line (Landis 1995). If prices effect vary across space, then the incentives that induce land use change will vary as well.

Where hedonic models describe short-run changes in value, density models describe changes in land use, population and employment and other long-run changes in the urban landscape. The most common methodological approaches for density studies are systems of simultaneously estimated equations of population and employment and discrete choice models of land use change. These studies aggregate their unit of spatial analysis to areas around stations. Data tend to be limited, so most of these studies do not investigate LRT's effects on use at the property level. Table 3.2 summarizes results from some key studies.

The results of density change studies are less consistent than hedonic studies. Land use, population and employment densification varies across space and is difficult to attribute directly to changes in accessibility. Bollinger and Ihlanfeldt (1997) use a simultaneous equation model and find no discernable changes in population and employment in Atlanta after the MARTA transit system opened. Studies using discrete choice analysis of land use change have typically found large discrepancies between the rate of land use change at different stations along the line (Paez 2006; Cervero and Landis 1997).

Table 3.2 Examples of Density Change Studies

Author Name (Year)	Geographic Area	Methodological Type (Geographic Unit of Analysis)	Dependent Variable(s)	Analysis	Results
Geotz et al (2010)	Minneapolis: Hiawatha	Summary statistics over time (station area buffers)	Various indexes of land use	Effects of station areas on land use mixes	One year after line completion, land use shows no discernable changes.
Paez (2006)	San Francisco: BART	Discrete choice model with geographical weights (10 hectare squares)	Binomial dependent variable (1=land use changed, 0=unchanged)	Is the assumption of constant coefficients across space reasonable?	Price effect varies spatially and geographic weighted models fit better than global models.
Irwin and Bockstael (2004)*	Urban-Rural Fridge: Patuxent Watershed	Discrete choice model (properties)	Binomial dependent variable (1=land use changed, 0=unchanged)	At what point do future income streams from converted use exceed conversion costs?	Identified numerous variables that deter and promote land conversion.
Cervero and Landis (1997)	San Francisco: Bart	Summary statistics, ridership surveys, matched pairs: station areas & freeway areas (station area buffers)	Summary stats of population/employment/ridership. Matched pairs regression of land use change.	Effect of BART on population/employment growth and land use change. Factors inducing land use change.	Uneven effects across metropolitan region for all variables. Land use change affect by area land-use mixture, park and ride lots, employees per acre, vacant land, freeway distance.
Bollinger and Ihlanfeldt (1997)	Atlanta: MARTA	Before/after: simultaneous equations (census blocks)	Population/employment	Effect of MARTA on total population and employment in station areas	No discernable effects
Landis et al (1995)	Five California Systems	Logit model (10 hectare areas)	Multinomial (vacant to residential, vacant to commercial, etc)	Effects of LRT to increase probability of certain land use changes within station areas.	1965-1990, parcels within station areas had a higher probability of changing uses.

*While not a light rail effects study, this paper models the decision to convert land use from the perspective of the land developer.

Other studies also bring up issues of endogeneity—perhaps light rail transit is built in areas with *inherently* more active land markets. If the potential for land use change is driving location decisions for LRT investment, then we run into serious empirical problems identifying the unique effect of LRT on land use change (Devett et al 1980). Another obstacle is separating the influence of rezoning policies and government intervention.

For the most part, land use studies done too early after LRT investments find a high degree of variation in development patterns. Those few studies that examine effects over several decades have shown LRT proximity has considerable influence on the probability of land use change (Landis et al 1995; Cervero & Landis 1997).

These inconsistent findings on the effects of LRT challenge the prevailing notion that LRT can be reliably used by city planners to induce urban land use change. Given that automobile transit is pervasive and relatively cheap, some argue the marginal increase in accessibility from LRT is too small to change household's and firm's location decisions, especially considering the fixed costs (Giuliano 1995; Cervero and Landis 1995).

4. Data

I hypothesize that LRT investment changes location accessibility of properties near stations, increasing demand for those properties, and thus providing developers with incentives to convert properties to more profitable, denser uses. This effect should be different across properties depending on property use.

In an ideal experimental situation, I would test my hypothesis using two identical areas of heterogeneous land uses populated with an identical set of land developers, introduce light rail improvements to one of the areas, and conduct a matched pairs test. Because this experimental technique is not possible, I estimate the effects of distance to the Hiawatha Line light rail stations in Minneapolis on land use change during LRT construction (2000 – 2004) and in the first six years of operation (2005 – 2010), controlling for location, property, neighborhood, and land use covariates. I focus only on Minneapolis due to data disparities between the different municipalities that contain the Hiawatha Line. Additionally, three of the stations to the south of Minneapolis are unique situations that should be considered separately: two airport stations and a station in the Mall of America complex.

I construct the data using parcel information from Hennepin County for properties in Minneapolis. I use Geographic Information Systems (GIS) to match parcel information with land use at the same location in 2000, 2004, 2005 and 2010. Land use data for 2000 - 2004 come from the Metropolitan Council's Generalized Land Use Survey (GLUS)—a large data set based on a combination of remote sensing and parcel information. For 2005 – 2010 land use data, I use the 2005 and 2010 parcel dataset's use descriptions from Hennepin County.

There are a few problems with these data. The two land use data sets categorize land use under different coding systems. In order to compare these two datasets, I aggregated land use into five categories: Vacant Land (no buildings), Low-Density Housing, High-Density Housing, Industrial and Commercial. These categories simplify the conversion analysis, identifying broad trends in conversion and clearly demarking whether that conversion represents a change in density. However, there are some disparities between the datasets. Table A.1 in the appendix shows the categorization.

Even after aggregation, the two land use sets report different land use mixes within 1-mie of the LRT. Comparing the end of 2004 land use mix from the Generalized Survey and the end of 2005 land use mix from parcel data, we can see there exist some discrepancies in classification:

Table 2: Reporting Discrepancies Across Periods

	Generalized Survey	Parcel Data	Difference in Land Use Reported (Generalized - Parcel)
Vacant Land	421	1678	-1257
Low Density Housing	12230	12138	92
High Density Housing	1477	1431	46
Industrial	3317	2499	817
Commercial	3854	3553	301
Total Acres	21298	21298	0

The largest discrepancies exist in vacant, industrial, and commercial property classification. The parcel data set has 1257 more acres of classified as vacant land and 817 less acres classified as commercial land than GLUS. Deeper investigation reveals that the GLUS survey, because it is based on aerial photography and limited parcel information, tends to report some properties as occupied, but in the parcel database, the property is owned by a separated entity (and vacant). Because of these differences, I am wary of combining the data into a panel dataset. In the analysis and results section, you will find that I have run regressions on the two time periods separately. Occasionally, I will pull out the vacant building category to examine specifically what happens in from 2005 – 2010 with vacant buildings. This separation is only possible with the for the parcel dataset classification system, not GLUS.

Previous studies have agreed on other covariates that affect land use. These variables come from several sources and were calculated and collated in ArcGIS. Using GIS, I calculate the Euclidian distance between properties and LRT stations, the CBD, and major highways and parks; determine the majority land use in the surrounding neighborhood; and connect each property with applicable 2000 Census blockgroup information.

Given the theoretical framework discussed in Section 2, these covariates help control for other factors that might affect demand for a particular location in the city or costs of conversion. The location covariates control for accessibility differences; the neighborhood variables control for property demand disparities that may arise from differences in amenities, disamenities, existing housing stock, and residents' preferences about race and income; the property characteristics control for heterogeneous property attributes that might affect developer costs. Table 4.3 summarizes the variables I have for 21,117 properties within one-mile of Hiawatha Line stations:

Table 4.3 Summary of Variables
Variable names and definitions

Variable name	Definition	Source	Mean	Standard Dev.	Minimum	Maximum
Dependent Variable						
USECHNG00_04	Equals 1 if USE00≠USE04	GLUS	0.033	0.178	0.0	1.0
USECHNG05_10	Equals 1 ifUSE05≠USE10	Parcel Data	0.032	0.177	0.0	1.0
Land Use Variables						
USE00	generalized land use in 2000	GLUS	2.355	0.934	1.0	5.0
USE04	generalized land use in 2004	GLUS	2.356	0.915	1.0	5.0
USE05	generalized land use in 2005	Parcel Data	2.203	0.847	1.0	5.0
USE10	generalized land use in 2010	Parcel Data	2.215	0.855	1.0	5.0
Distance Variables						
*Dist*LRT	Distance (feet) to LRT station	calculated	955.571	372.320	15.5	1882.8
*Dist*CBD	Distance (feet) to downtown Minneapolis	calculated	5249.324	2419.722	15.1	10148.1
*Dist*HWY	Distance (feet) to nearest highway	calculated	676.025	390.664	10.8	1630.1

DistPark	Distance (feet) to nearest park	calculated	358.570	206.380	0.0	1060.2
DistLake	Distance (feet) to Lake Street commercial corridor	calculated	2236.184	1516.315	2.5	5845.9
Neighborhood Variables						
MED_INCOME	blkgrp median household income	2000 Census	39236.680	12783.900	0.0	176246.0
POP_DENSITY00	blkgrp population per square-mile 2000	2000 Census	8235.775	4485.295	25.0	38890.0
POP_DENSITY08	blkgrp population per square-mile 2008	2000 Census update	8701.673	4957.968	1088.2	46070.0
PER_WHITE	blkgrp percent of population white	2000 Census	70.489	21.244	7.7	100.0
PER_BLACK	blkgrp percent of population black	2000 Census	12.565	11.434	0.0	62.7
PER_HISP	blkgrp percent of population Hispanic	2000 Census	8.679	8.938	0.0	41.7
PER_NATIVE	blkgrp percent of population Native American	2000 census	4.902	5.320	0.0	76.1
PER_ASIAN	blkgrp percent of population Asian	2000 Census	3.780	3.402	0.0	43.7
PER_VACANT	blkgrp percent of housing units vacant	2000 Census	3.261	3.395	0.0	38.4
PER_COLLEGE	blkgrp percent of population with college education	2000 Census	13.909	6.831	0.0	31.5
MED_AGE	median age of population in blkgrp	2000 Census	34.622	6.034	17.2	76.7
MED_Yr_BUILT	median year built for all buildings in blkgrp	2000 Census	1936.120	125.266	0.0	1983.0
Property Variables						
ACRES2000	property acres in 2000	Parcel Data	0.256	1.059	0.0	61.5
ACRES2005	property acres in 2005	Parcel Data	0.245	1.041	0.0	61.6
EMV00	estimated market value of property 2000 nominal dollars	Parcel Data	311222.100	2847370.000	0.0	155000000
EMV05	estimated market value of property 2005 nominal dollars	Parcel Data	341826.500	2497106.000	0.0	131000000
MixUse00	majority land use in the neighborhood is mixed 2000	calculated	0.002	0.048	0.0	1.0
MixUse05	majority land use in the neighborhood is mixed 2005	calculated	0.226	0.419	0.0	1.0
NON-MAJ USE00	equals 1 if property is not in the majority use in 2000	calculated	0.198	0.399	0.0	1.0
NON-MAJ USE05	equals 1 if property is not in the majority use in 2005	calculated	0.226	0.419	0.0	1.0
REZONED	property in an area subject to city rezoning from LRT	Minneapolis Zoning Administration	0.029	0.168	0	1

GLUS: General Land Use Survey, , Parcel Data: 2000 - 2010 Metropolitan Council Parcel Dataset, Calculated: Calculated in ArcGIS

5. Hiawatha Line – A Geographic Introduction

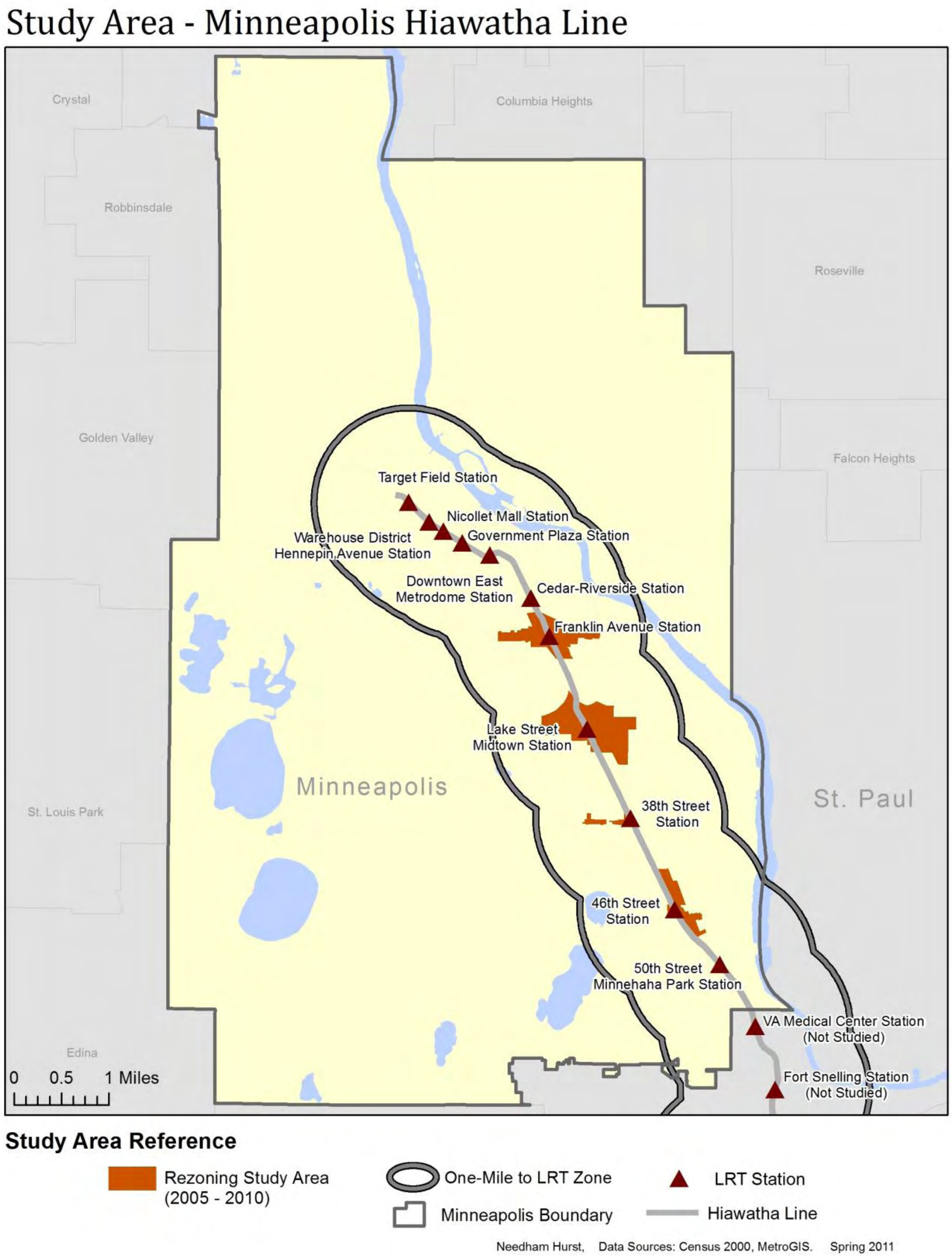
The Hiawatha Light Rail Line runs between downtown Minneapolis in the north and the Mall of America in the south. It was constructed between 2001 and mid-2004. The 12.3-mile line consists of 19 stops, including two airport terminals stations, the Mall of America station, several neighborhood stops and downtown stations (MetroCouncil 2010). A large swath of the east side of the line between the 46th Street Station and the Franklin Avenue Station is an industrial strip. As we see later, that industrial land use began to wear away in the face of growing housing demand near the line between 2000 and 2007. The line averages about 30,500 rides per weekday and is used to access downtown entertainment, sports events, and employment centers (MetroCouncil 2010). For this study, I only use the Minneapolis portion of the Hiawatha Line (50th Street Station to Target Field Station) as portrayed in Map 5.1. The summary statistics and regression results that follow are only for the areas near the 11 Minneapolis stations.

For most of the 12.3 miles, the line runs along Hiawatha Avenue—a state highway and major north-south thoroughfare. Land use along the line consists of several different zones. It cuts through the Lake Street commercial corridor, home to many small minority-owned businesses and other commercial properties. At the Cedar-Riverside Station, the last stop before the downtown area, high-rise apartments mark the transition between medium-density townhouses and duplexes to the south and high-density apartment buildings in the downtown area.

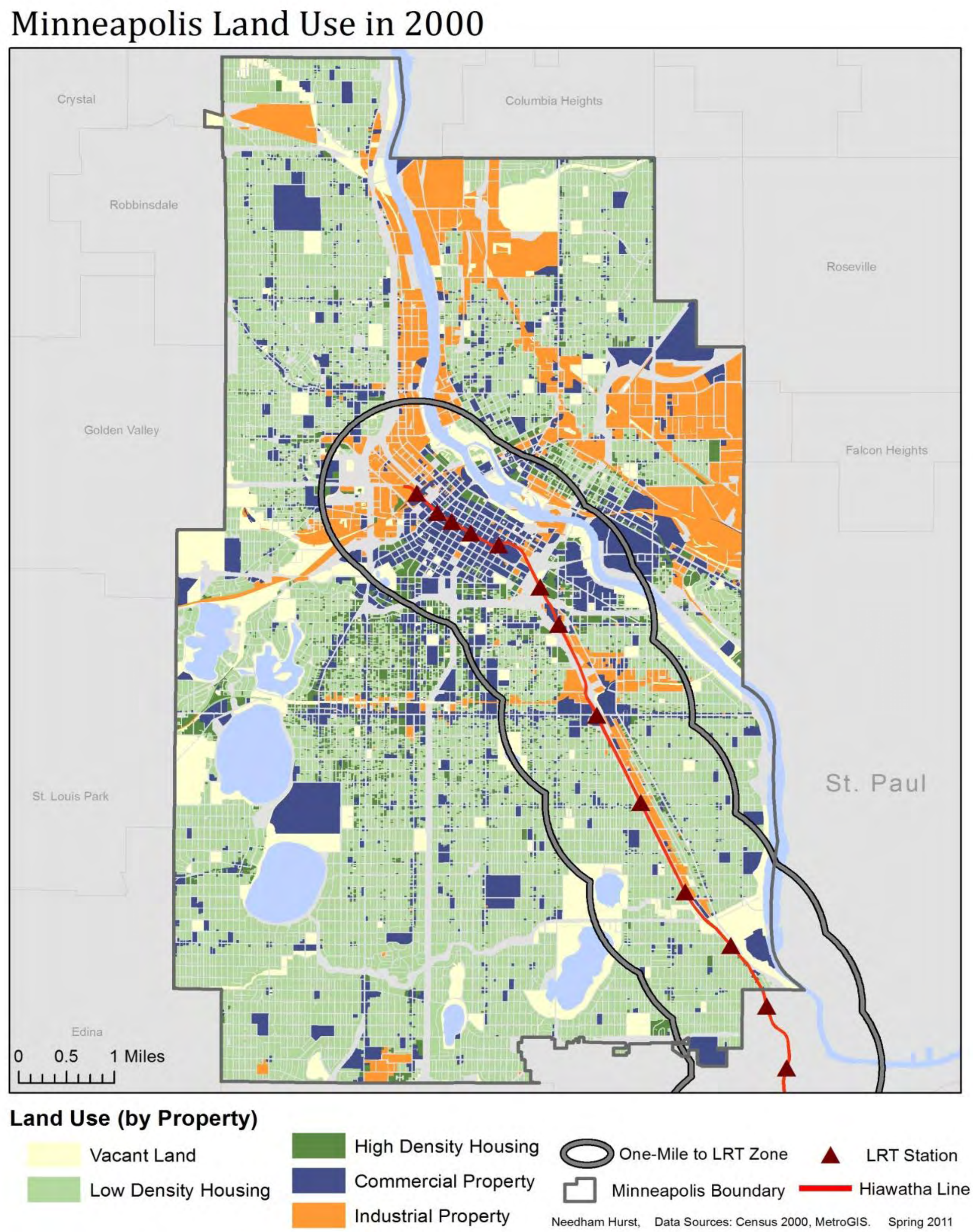
Map 5.2 shows much of the land to the east of the line was used for medium and light industry in 2000. By 2010, the city overall had many more vacant properties. Near LRT stations, we see some small but noticeable changes near the downtown Target Field Station and in highly industrial areas (Map 5.3).

In Minneapolis, the line runs through some of the most racially and economically diverse neighborhoods in the city. Within one mile of the LRT are several neighborhoods with high population density, especially near downtown. As distance from the CBD increases, we see less density and more single-family homes. As shown in Maps 5.3 – 5.13, neighborhoods near the line include much of the Hispanic population (Lake Street/Midway Station), a portion of the African American community (particularly in south Minneapolis), and parts of the predominately white neighborhoods along the river and to the south.

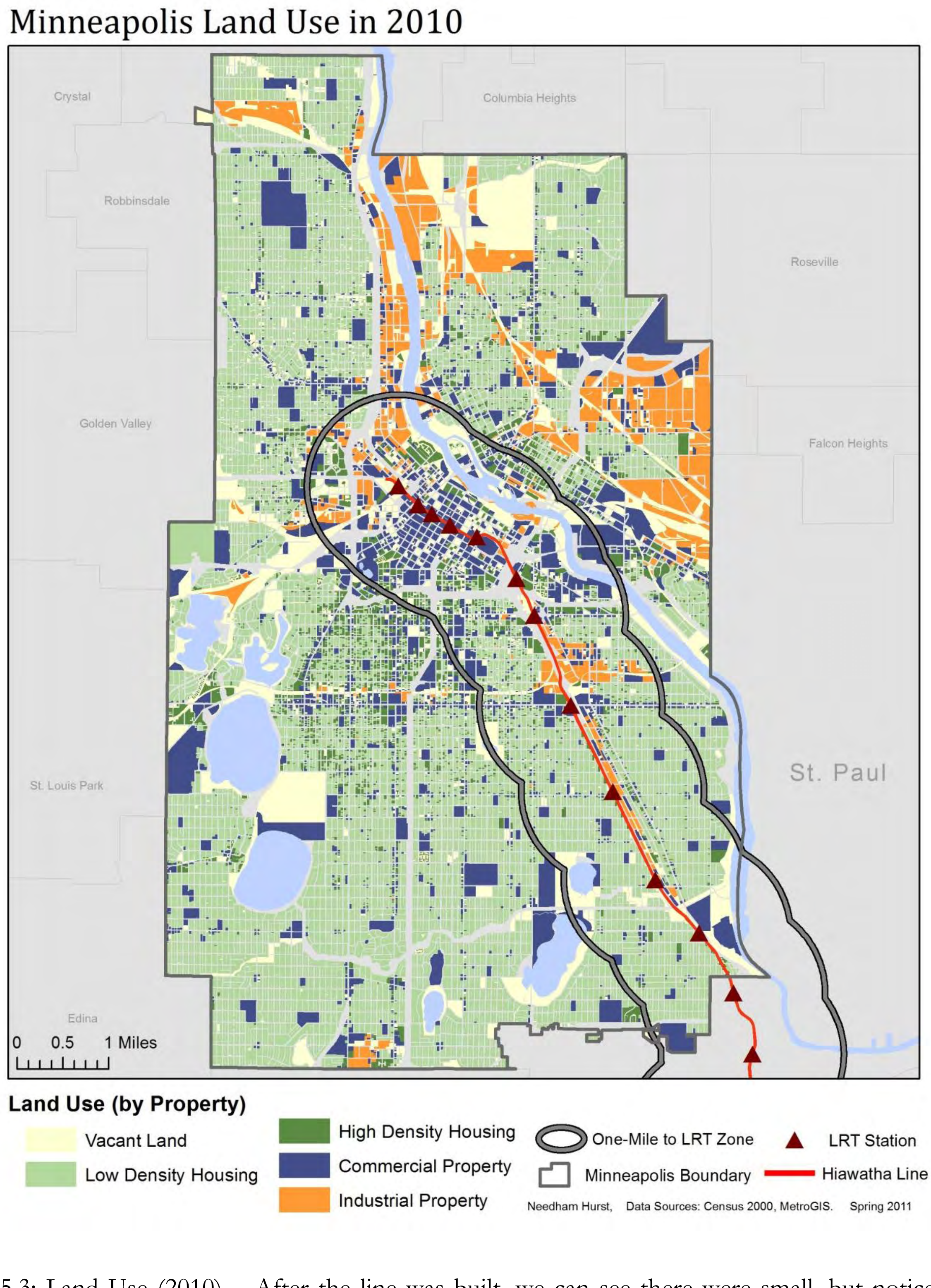
The housing situation along the line is equally diverse. Home vacancy is higher near the CBD than near the southern part of the line. This pattern follows the spatial distribution of average tenure of residents and home ownership. The home-ownership map is particularly striking. Throughout much of the urban core less than 1/3rd of all units are owner-occupied.



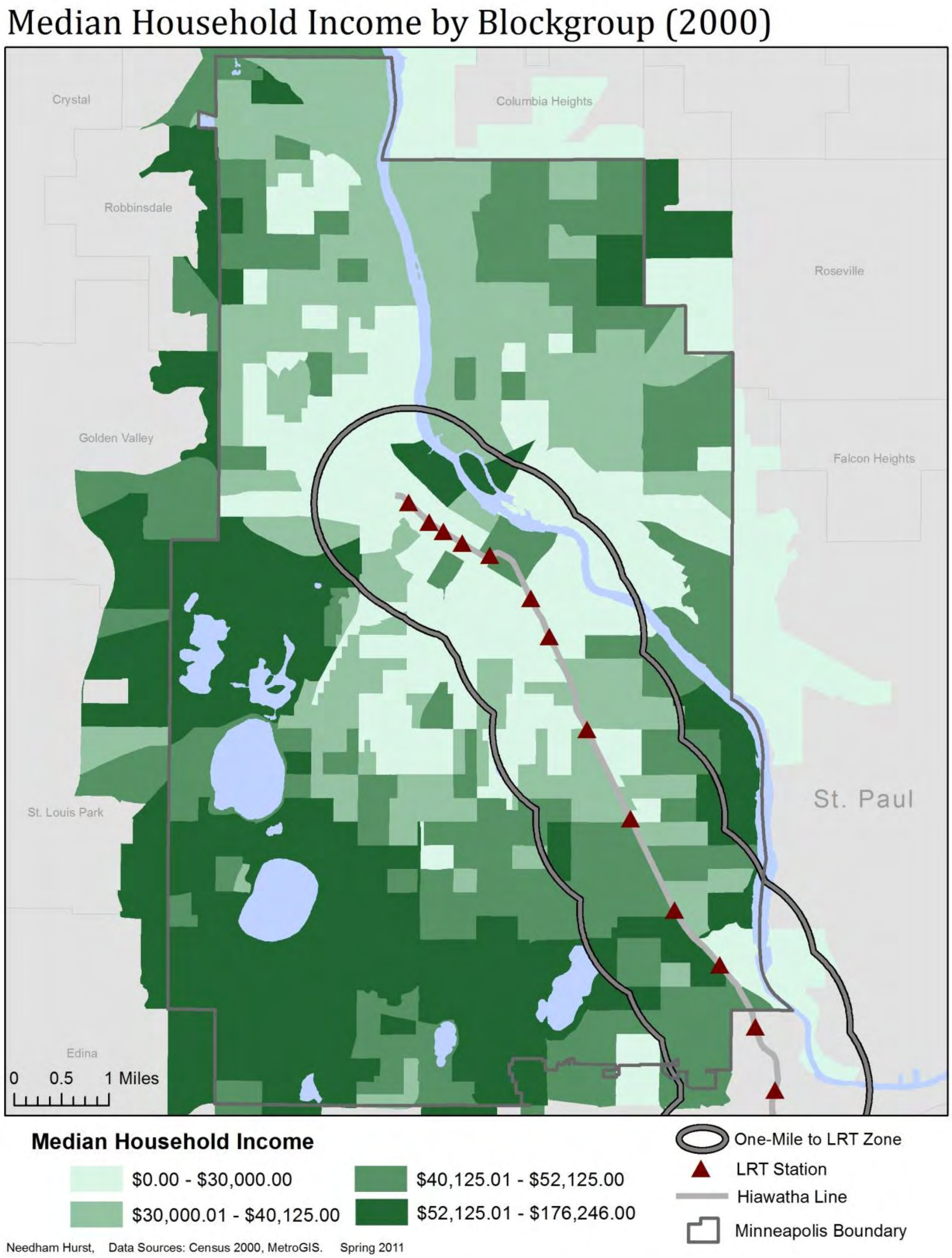
Map 5.1: Study Area – I examine properties within one-mile of 11 Minneapolis station areas. This map also shows the boundaries of the city-led rezoning studies conducted between 2005 and 2010.



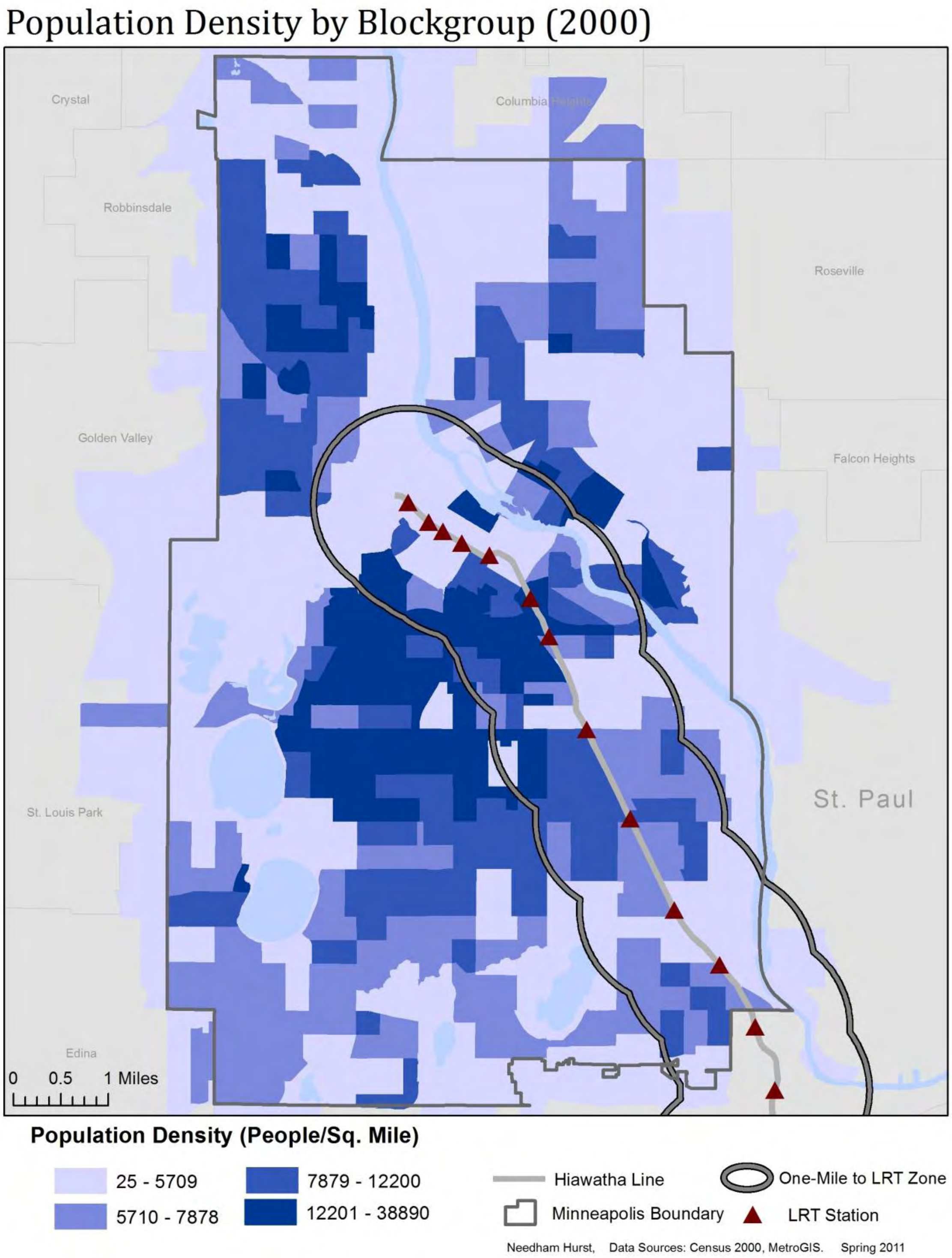
Map 5.2: Land Use (2000) – The Hiawatha Line runs along an industrial corridor surrounded by low density housing in the south, cuts through the Lake Street commercial corridor and into the more dense downtown area.



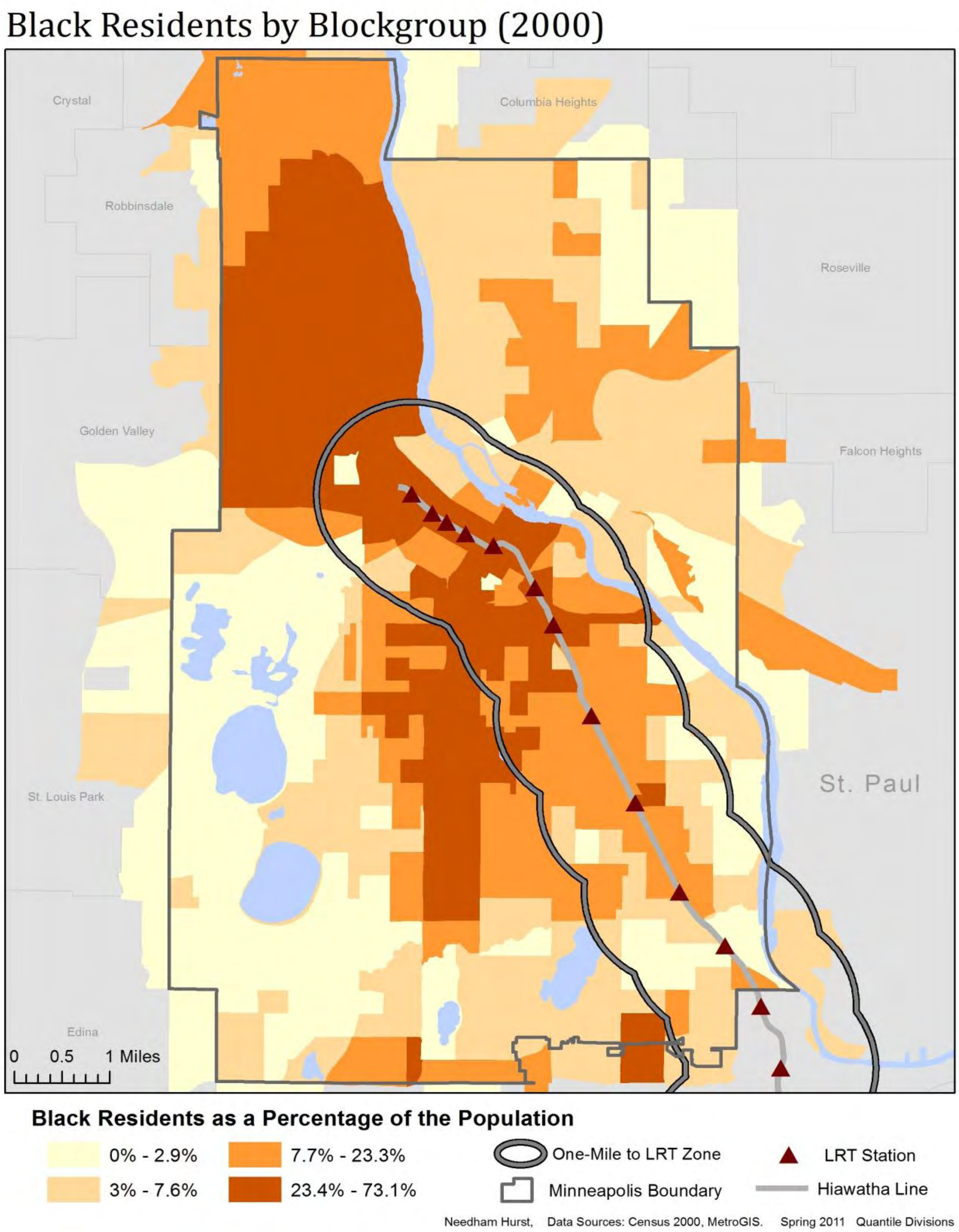
Map 5.3: Land Use (2010) – After the line was built, we can see there were small, but noticeable changes along the corridor and at station areas. In 2010, there were overall many more vacant properties throughout the city than in 2000—most likely due to the foreclosure crisis.



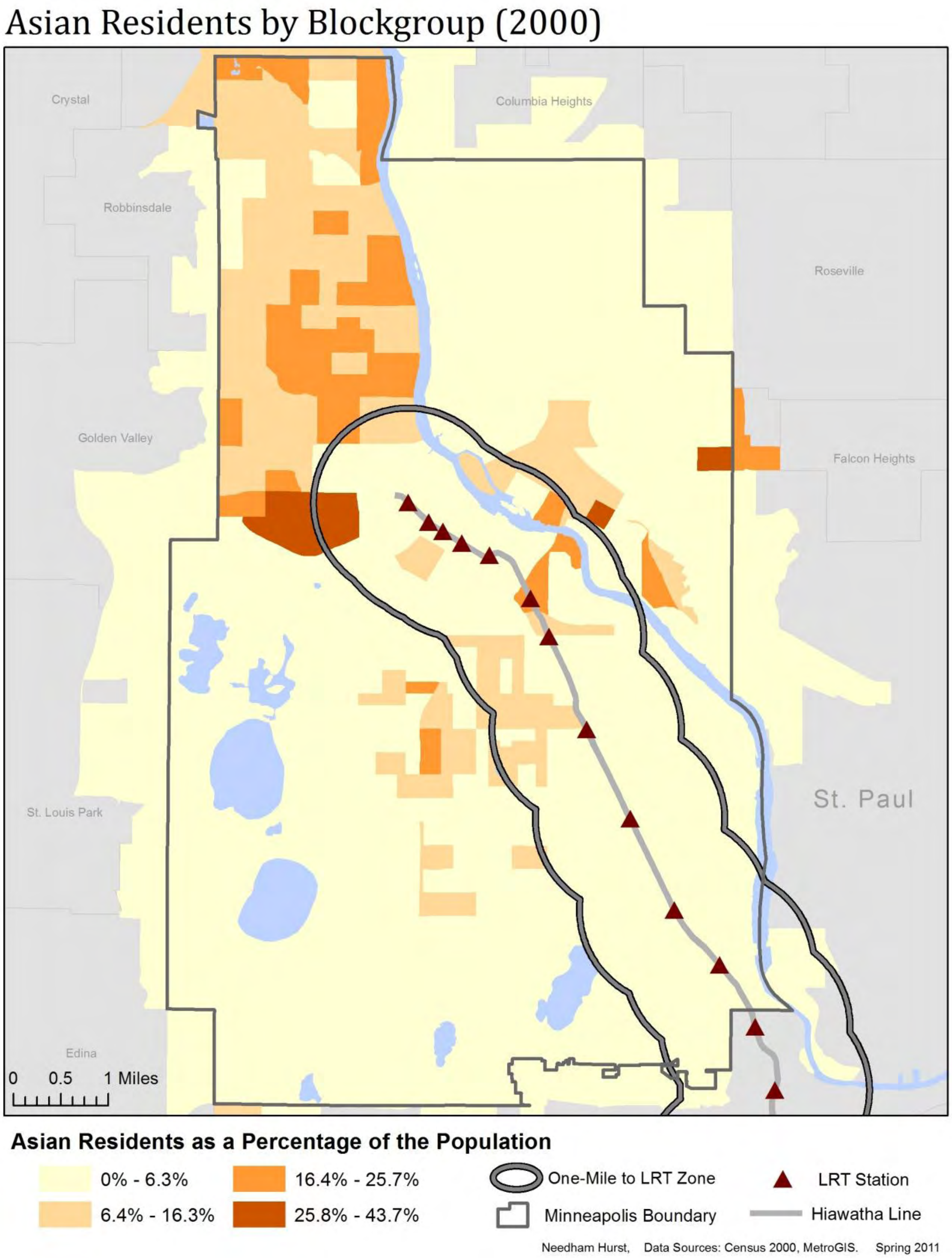
Map 5.4: Median Household Income – The Hiawatha Line alignment goes through a diversity of neighborhoods with respect to income, including some of the lowes- income areas of the city.



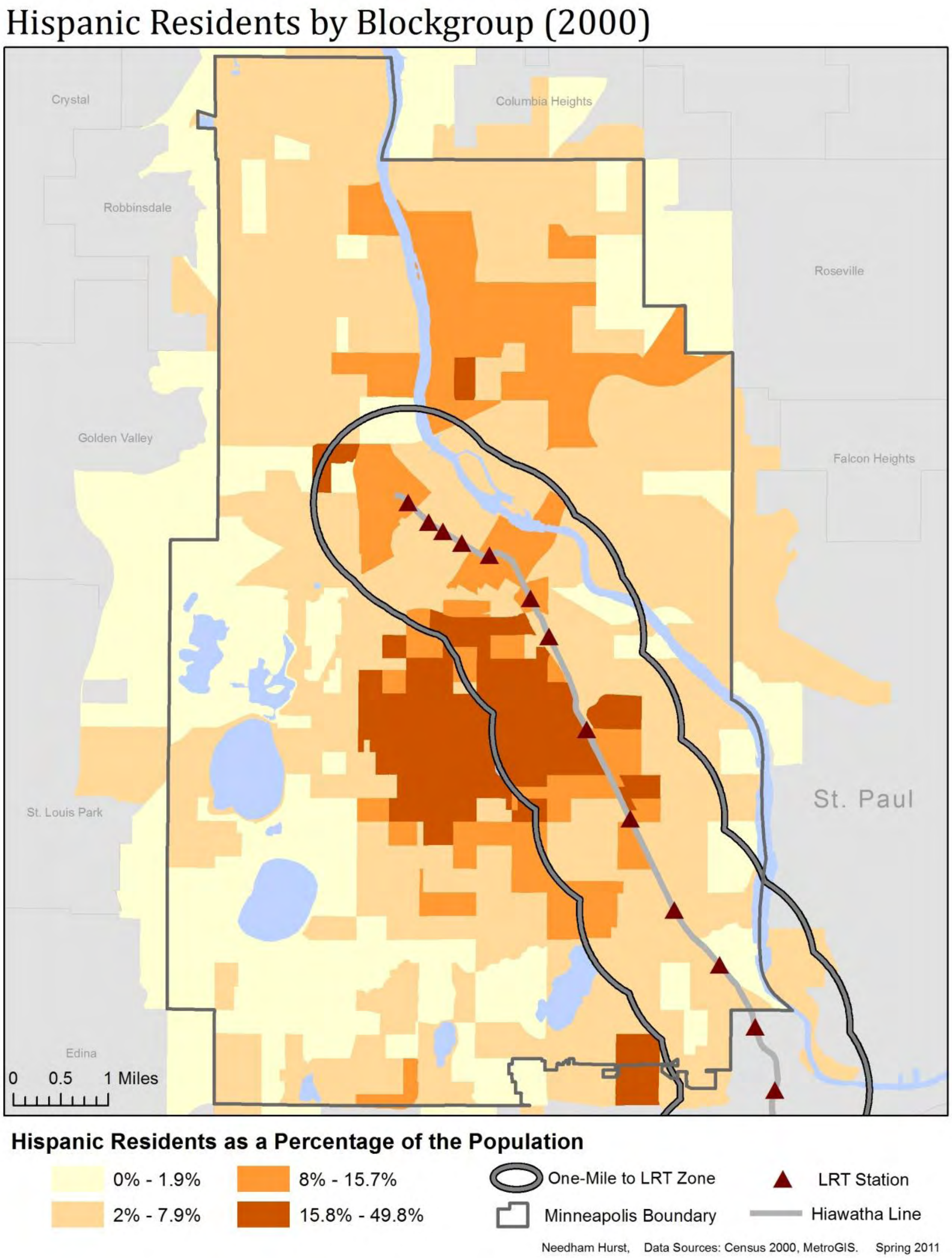
Map 5.5: Population Density – Population density is higher near midtown and the CBD than the southern part of the line.



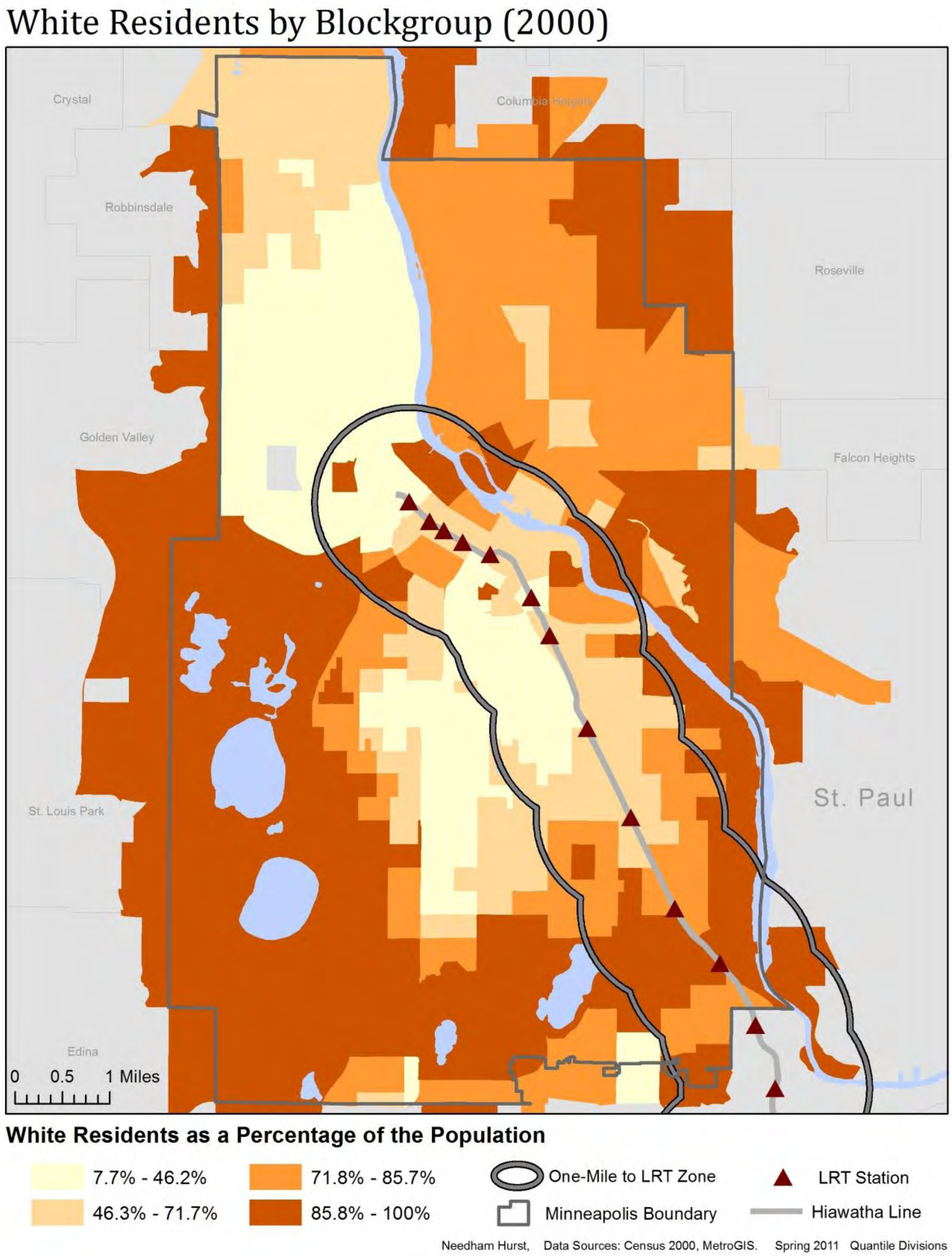
Map 5.6: Black Residents – The line passes through areas with high populations of African Americans.



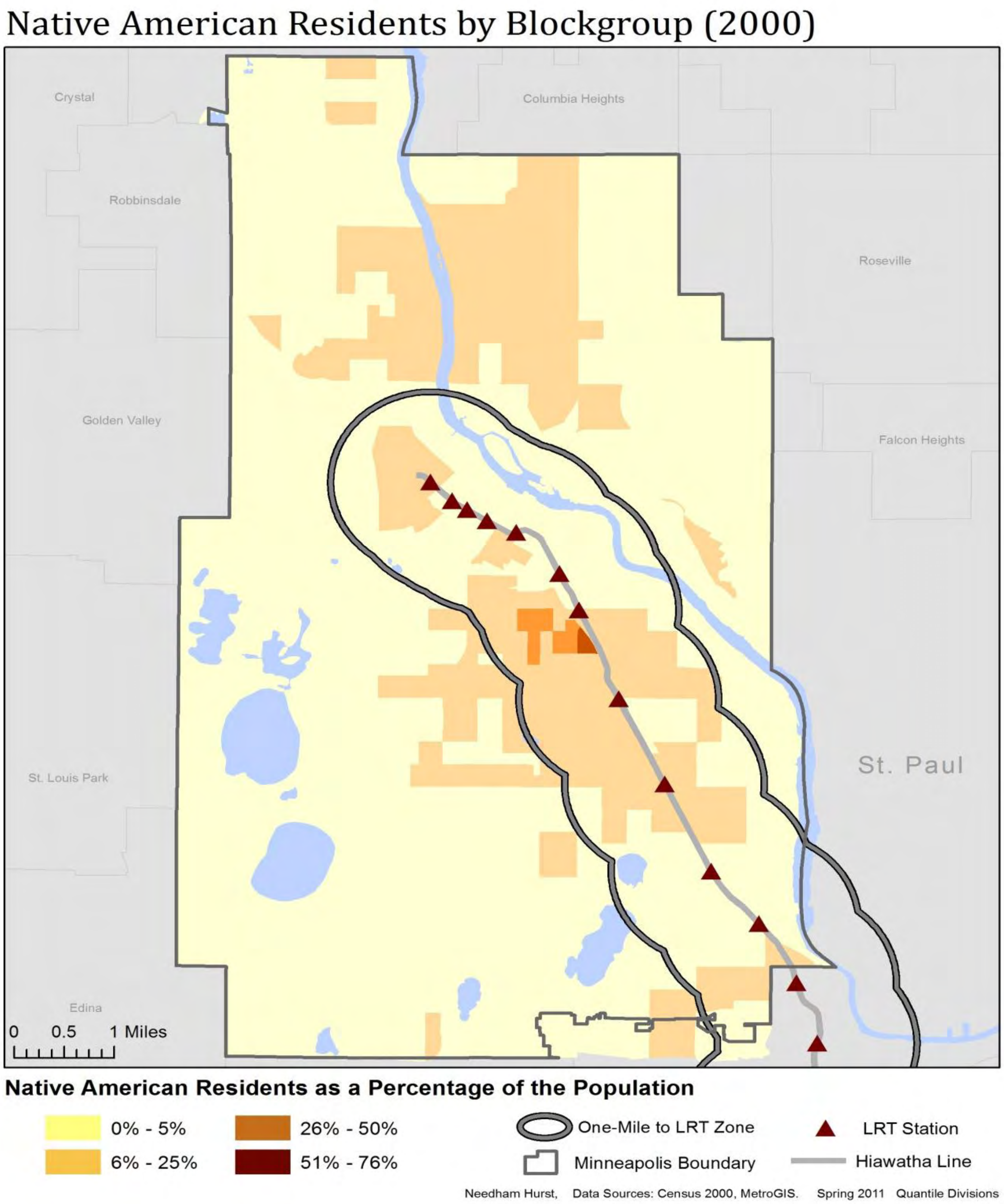
Map 5.7: Asian Population – There is a fairly low population of Asian residents across all of Minneapolis, but the Hiawatha Line does affect some of those areas.



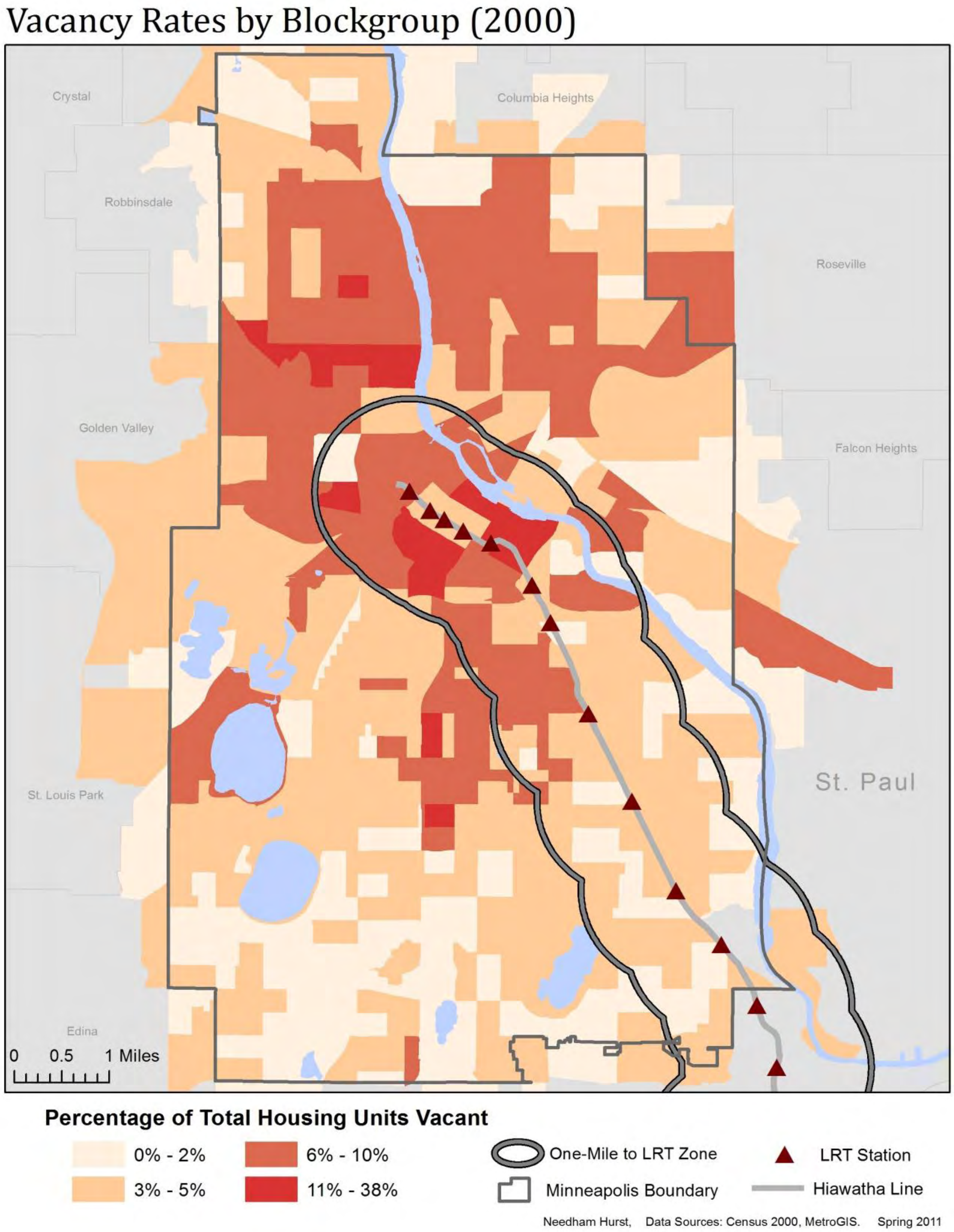
Map 5.8: Hispanic Population – The neighborhoods near the Lake Street and Franklin Avenue stations have some of the highest density of Hispanic residents in the city.



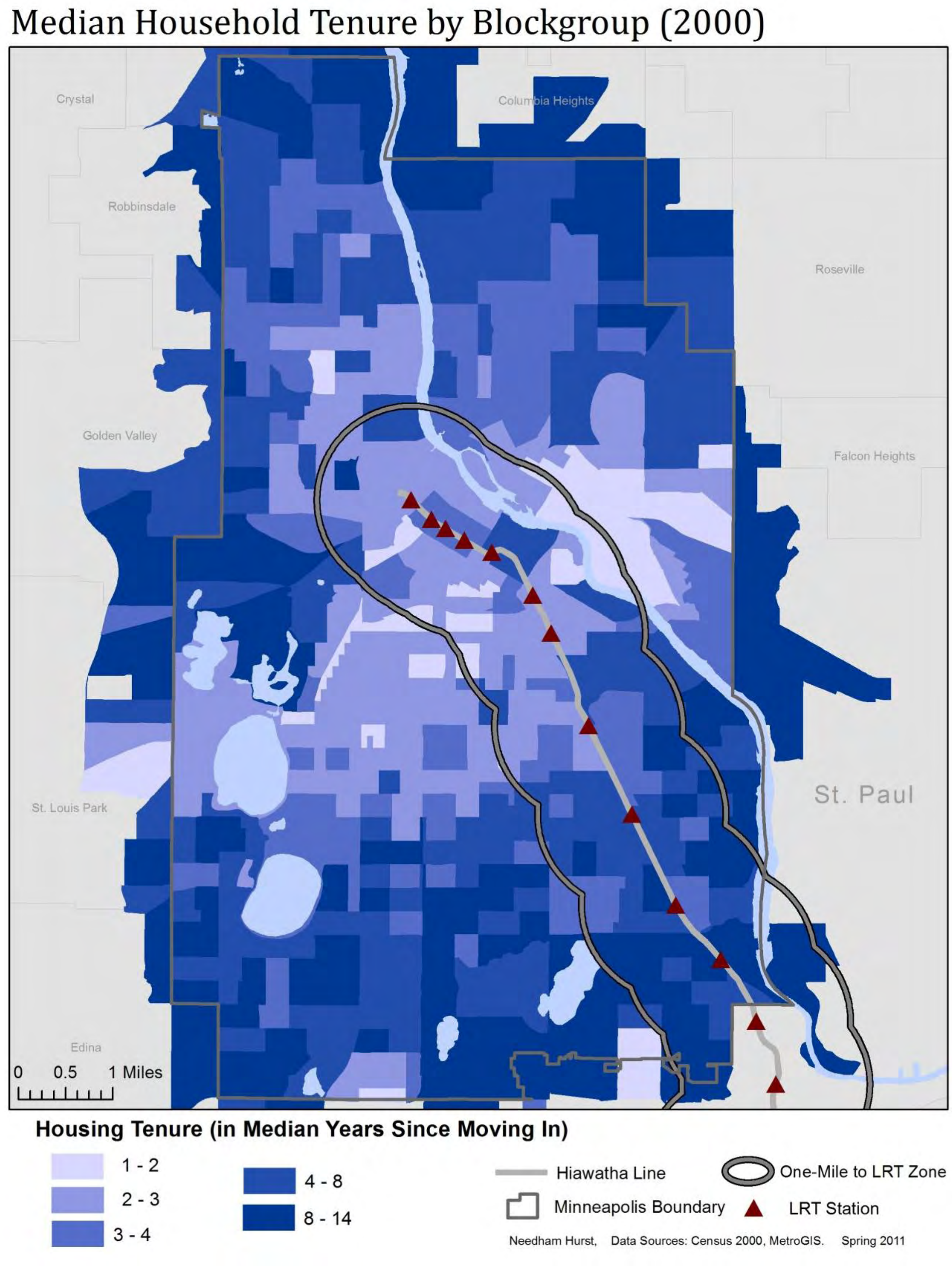
Maps 5.9: White Population – In general, there is a density of white residents toward the southern part of the line.



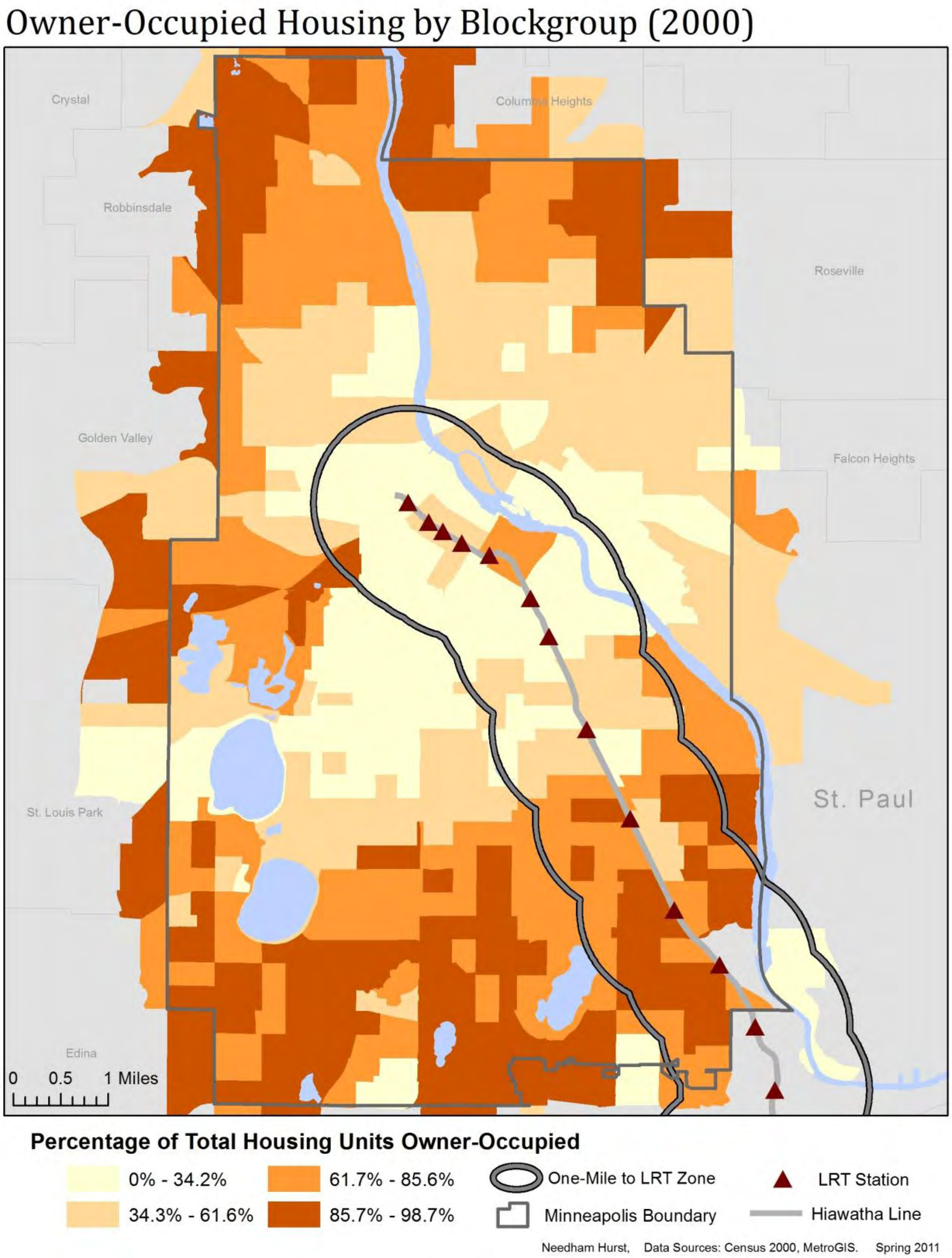
Maps 5.10: Native American Population – Minneapolis has a large population of Native Americans living in the city. Many reside in Little Earth, a tribal housing authority development near the Franklin Avenue Station.



Map 5.11: Vacancy Rates (2000) – Vacant properties were primarily concentrated near the CBD. The southern part of the line was relatively unaffected by vacancies in the early 2000s.



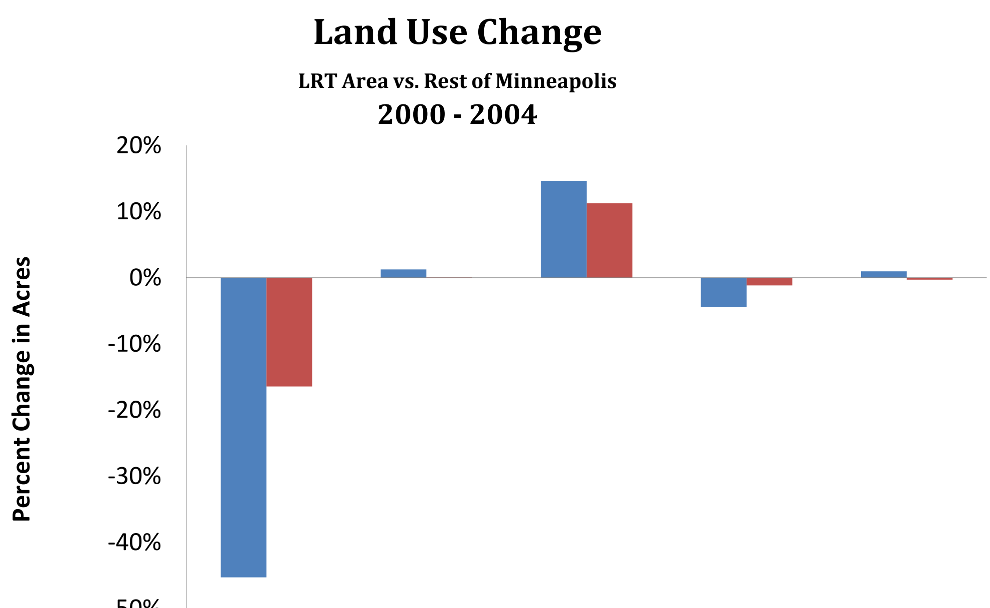
Map 5.12: Housing Tenure – Housing tenure follows income and population density covariates—shorter tenure toward the city center, longer tenure toward the city edge.



Map 5.13: Owner-Occupied Homes – Housing tenure and owner-occupancy show very similar spatial patterns.

3.2 Land Use Change

Both before and after the LRT opened, there was a higher percentage of land use change within one mile of the Hiawatha Line than the rest of Minneapolis.[3] The area within one mile represents about 1/4th of the city's total acreage. During planning and construction (2000 – 2004), the area near the LRT experienced an 45.3% drop in vacant land while the rest of Minneapolis only saw a 16.4% drop. This may be explained by land owners preemptively buying up vacant land in expectation of the Hiawatha Line. Similarly, acres of industrial property declined by 4.4% while in the rest of the city it dropped 1.1%. Chart 5.2 illustrates these trends.



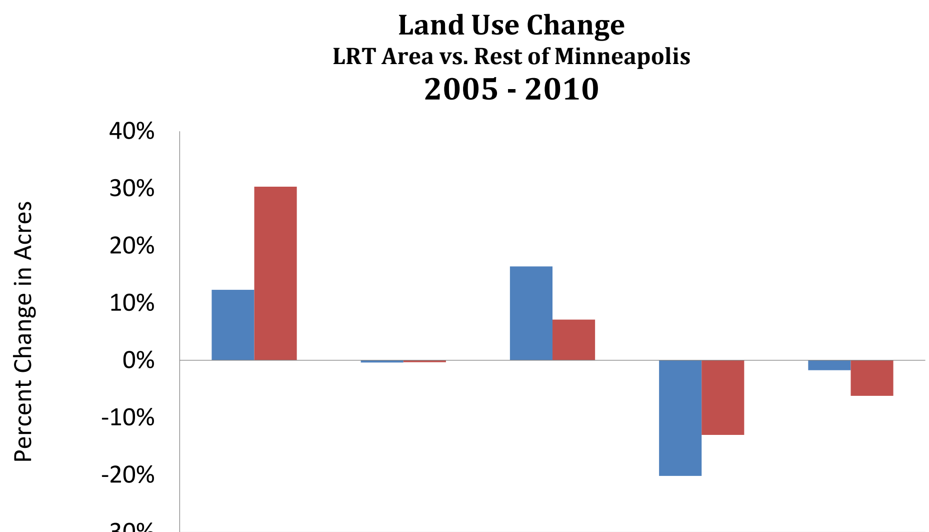
	Vacant	Low Density Housing	High Density Housing	Industrial	Commercial
Within 1-Mile of LRT	-45.31%	1.24%	14.64%	-4.41%	0.96%
Rest of Minneapolis	-16.43%	0.02%	11.26%	-1.14%	-0.31%

Chart 5.1: Land Use Change by Type, 2000 – 2004: Near the Hiawatha Line, land use change was slightly more active for all land use types than in the rest of the city.

[3] Specifically 4.8% of all acres changes use near LRT vs. 2.4% pre-LRT, and 7.2% vs. 5.5% post-LRT.

Most noticeably, acres for high-density housing increased by 14.6% near the LRT and 11.26% in the rest of the city. In both areas, this trend toward high-density housing was fueled by vacant and industrial land conversions.

After the Hiawatha line opened, land conversion activity increased in all areas of the city, but the difference between the neighborhoods near the LRT and the rest of Minneapolis was further intensified.



	Vacant	Low Density Housing	High Density Housing	Industrial	Commercial
Within 1-Mile of LRT	12.31%	-0.39%	16.37%	-20.16%	-1.72%
Rest of Minneapolis	30.29%	-0.36%	7.11%	-13.05%	-6.18%

Chart 5.2: Land Use Change by Type (2005 – 2010): After the Hiawatha line, the deindustrialization of land near the LRT increased. High density housing increased almost three times faster near the LRT than the rest of the city.

For every land use except low-density housing, the land use change trends diverged between the two areas. Vacant land increased by 12.31% near the LRT compared with 30.29% for the rest of Minneapolis. Land for commercial property remained stable near the LRT, while it declined 6.2% in the rest of the city. The foreclosure crisis and subsequent recession caused a spike in residential and commercial vacancies, particularly in North Minneapolis. If foreclosures and vacancies occurred near the LRT, these properties were quickly reused and reoccupied.

High-density housing and industrial land use change trends seen from 2000 to 2004 were further intensified after the Hiawatha Line opened. Land used for high-density housing increased 16.4% versus a 7.1% increase for the rest of Minneapolis. Land for industrial use decreased 20.2%, while in the rest of the city it dropped 13.1%. Both of these trends suggest that while the overall land conversion pattern is the same in both areas, the land market within one mile of the LRT was more active than the rest of the city.

These summary statistics appear to support the conclusion that price changes caused by LRT were enough to incentivize landowners to change land use. To determine if LRT is the causally related to land use change, I need to see that within the 1-mile area, a property near the Hiawatha line was more likely to change land use than one far from the LRT line, holding all else equal. There still exists the possibility, however, that the $1/4^{th}$ of the city within 1-mile of the LRT has an inherently more active land market--a topic I explore in detail in section 7.1.

6. Analysis and Results

6.1 Extent of LRT's Effect on Existing Land Use

I examine the correlation between distance to LRT stations and land use change using a binomial logit model. For this model, I only test the extent of LRT's land use change effect within the 1-mile study area (n = 21117 properties). I estimate five models, each increasing in complexity. In this section, I will discuss the results of the two most complete models—Models IV and V. The first three models will be used in the next section to identify robustness and endogeneity problems.

Table 6.1 Model Specification

Models	I	II	III	IV	V
Ln(DistLRT)	√	√	√	√	√
Land Use		√	√	√	√
Land Use * Ln(DistLRT)		√	√	√	√
Location Controls				√	√
Neighborhood Controls				√	√
Property Controls			√	√	√
Location * Ln(DistLRT)				√	√
Neighborhood *Ln(DistLRT)					√
Property *Ln(DistLRT)					√

For more details on each variable group, see Table 4.3.

Table 6.1 summarizes my model specification. Each set of control variables proxy for important location, neighborhood and property characteristics that may affect land use change.

In a logit model, the dependent variable equals 1 if the land use of a property changed between the beginning and end of the period. A logit constrains explanatory variables between 0 and 1 in order to estimate the probability of the dependent variable equaling 1. The logit regression's coefficients are reported as log-odds, rather than marginal effects, making outright interpretation difficult.

For distance to LRT, my main variable of interest, I expect the effect to be negative and larger in the second period—indicating that the presence of LRT provided incentives for land use change near stations. All distance measures are log-linearized in order to capture non-linear effects of location proximity.

The theory laid out in Section 2 indicates that location accessibility is a primary driver of changes in property prices. Properties in highly accessible locations may not see price jumps after LRT is installed because LRT may not change the marginal accessibility enough to generate higher housing demand. Without higher demand, the incentive structures faced by landowners will remain the same and land use change is unlikely to occur. Location controls proxy for initial accessibility by measuring each property's distances from the CBD, from a major highway, and from Lake Street—the primary commercial corridor in the sample outside of downtown. I hypothesize that these variables will each have a negative effect on land use change—as distance gets larger, accessibility (and therefore land use change) will decrease.

Neighborhood characteristics do not appear in the simplest form of the Alonso-Muth-Mills model, but it is not difficult to see how they might affect housing demand for an area. I use census data on block level racial characteristics, median income, population density, median age, home vacancy rates, the percent of the population with a college education, the median year built for buildings in the blockgroup, and distance to the nearest park to proxy for perceptions of the neighborhood, its amenities and disamenties. There are a number of different effects these neighborhood proxies might have, but because there is so much multicollinearity among these variables, I hesitate to make any assertions about the direction of the effects. Table 6.3 shows the correlation between the variables with greater detail. Notice that median income and college education are highly correlated with almost all of the other variables.

Finally, the property level controls evaluate land use change while accounting for the effect of heterogeneous properties. Parcel data and geospatial analysis supplies information on the initial estimated market value of properties in both 2000 and 2005, the size of the property in acres, whether a property's land use is consistent with the rest of the neighborhood, whether the property is in a mixed use neighborhood, and whether the property is an area that was subject to a city-led rezoning process (typically around station areas). The rezoning process was completed at different times for each station, the earliest was the Lake Street/Midway study in 2005 and the last is the 50th Street study, which is still in progress. The downtown stations were not part of the rezoning process. I hypothesize high market value properties and large properties are less likely to change land use, while non-conforming properties, properties in mixed-use neighborhoods and those in rezoning study areas are more likely to change land use.

Table 6.3 Correlation among Neighborhood Controls in Sample

	Income	Pop. Dens.	Median Age	% White	% Black	% Asian	% Hisp.	% Native Am.	% Vacant	% College	Med. Yr. Built
Income	1.00										
Pop. Dens.	-0.44	1.00									
Median Age	0.48	-0.32	1.00								
% White	0.77	-0.30	0.70	1.00							
% Black	-0.79	0.15	-0.50	-0.89	1.00						
% Asian	-0.46	0.12	-0.49	-0.56	0.42	1.00					
% Hispanic	-0.43	0.36	-0.65	-0.76	0.50	0.36	1.00				
% Native Am.	-0.43	0.36	-0.50	-0.64	0.40	0.16	0.48	1.00			
% Vacant	-0.34	-0.08	-0.23	-0.35	0.33	0.44	0.25	0.13	1.00		
% College	0.59	-0.31	0.58	0.69	-0.56	-0.35	-0.55	-0.51	-0.09	1.00	
Med. Yr. Built	-0.46	-0.03	0.05	-0.23	0.35	0.26	-0.04	0.04	0.27	-0.09	1.00

Data Source: 2000 Census

In Model IV & V, I use interaction terms between the distance from the Hiawatha Line stations and my covariates. This specification follows the more recent literature and allows for the effect of LRT on land use to be different for each covariate. Essentially, interaction captures the spatial heterogeneity of the LRT's effect on land use change.

6.3 Results

The results from Model IV and V confirm some of the findings from previous studies but also contradict previous findings (full results table in Appendix I, Table A.2). The range of the effect of LRT on land use change is limited to between 55 and 150 feet from stations for all uses except vacant and industrial properties. The small range suggests the marginal decrease in transportation costs is only big enough to change land use very near stations. Table 6.4 compares previous research and the findings of this study.

Table 6.4 Previous Findings vs. Results of This Study

Vessali's Summary of Empirical Findings	Results of This Study
1. Land use impacts of transit are observed, but they tend to be small for heavy rail systems and even smaller for light rail systems.	LRT affects land use within only within 90 feet in areas with low-density housing. High density and commercial properties within 150 feet experienced some land use change. Vacant land experienced the biggest effect, and industrial land experience change, although not necessarily responsive to distance from stations.
2. There is mixed evidence that the impacts are smaller in high income areas.	Comparing Maps 5.2 and 6.2, there appears to be spatial correlation between neighborhood median income, race and land use change. Regression analysis confirms this result controlling for other factors (Appendix I).
3. Access to transit has an average price premium of six to seven percent for single-family homes.	NA
4. Transit access has a mixed and inconsistent effect on commercial property values.	NA

5. For systems that run from the central city to the city edge, areas near the city edge experience the greatest land use impacts because there is more room for development.	More land use change toward city-center. Narrow effect in residential areas.
6. Transit-oriented development tends to transfer development from other areas of the metro area, rather than create new growth for the region.	NA
7. Around transit stations, commercial uses tend to replace residential and industrial uses over time, but residential growth is very noticeable along the transit corridor.	Commercial properties very unlikely to change land use until after LRT is built. High density housing increases.
8. A few studies that compared transit affects on residential vs. commercial find mixed results as to which type experience more profound effects.	NA
9. Almost exclusively, transit systems' impacts on land use are limited to rapidly growing regions with healthy underlying demand for high-density development.	Inconclusive, but LRT appears to hold down vacancy rates when compared with the rest of the city.
10. Public sector involvement (i.e. zoning, land assembly, restrictions on parking, TOD incentives) is common enough to be considered necessary. Some even claim that transit investment may drive policy changes, which affect land use more than the transit itself.	Properties without rezoning had a 3% probability of land use change, while equally proximate properties in rezoning areas had a 5.5% probability of land use change, controlling for all other variables.

Interpretation of the coefficients in Model IV and V is difficult once control variables and interaction terms are present. Charts 6.1 – 6.5 make interpretation clearer.[4] The charts give the estimated probability of land use change for different types of properties as distance from the Hiawatha Line increases, evaluating the effect of LRT across distance while evaluating all other

[4] Model IV is used to generate the marginal probability charts below because model V includes interaction terms between categorical variables and distance, making marginal effects un-interpretable at mean values for all covariates.

covariates at their means. Standard error bars show the 95% confidence intervals for estimates at each distance.

Notice that for most uses, the difference in predicted probability between the two periods is statistically significant. For the most complex model, Model V, interpretation requires mapping the predicted probabilities for each property. Maps 6.1 – 6.4 show the fitted model spatially and then maps predicted land use change vs. actual land use change. The tabular, logged odds form of the estimation results is in Appendix I.

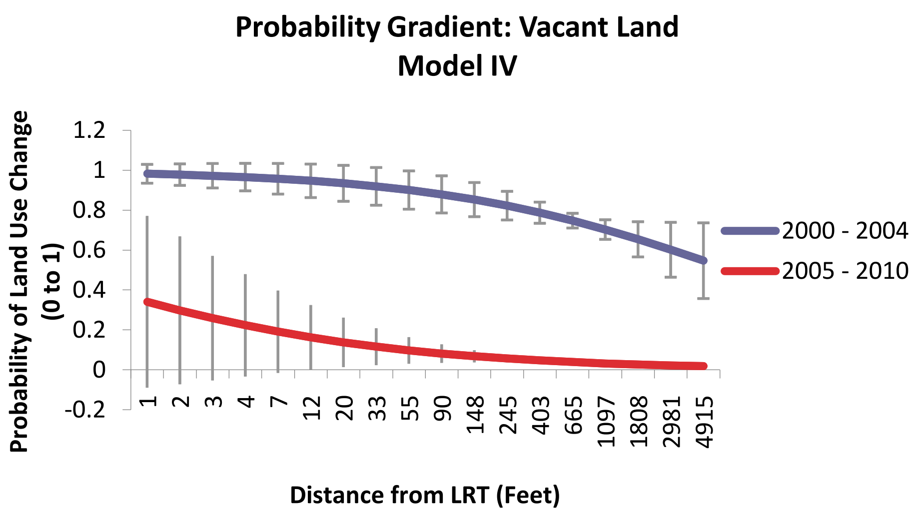


Chart 6.1 Vacant Land

The probability of land use change for vacant land was almost 1 near the LRT during construction. After construction, the probability of land use change drops to .4 near the LRT, most likely because there was not much vacant land left after 2004. In both cases, the range of LRT's effect on land use change is quite long, going all the way to the edge of the one-mile area.

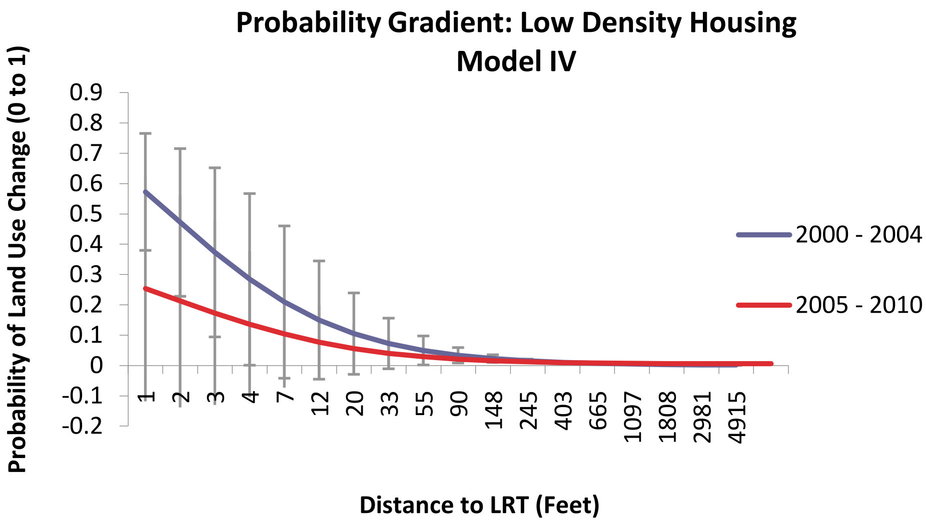


Chart 6.2 Low Density Housing

Low-density housing near the LRT was somewhat likely to change land use between 2000 and 2004, but after 2004, the probability was much lower. In both periods, the radius of LRT effects on land use change only goes out to about 150 feet from stations. This pattern illustrates that landowners with less capital intensive properties (single-family homes) were very willing to change land use, but only if it was near a station. There may also be political reasons why we see much fewer changes in low-density properties.

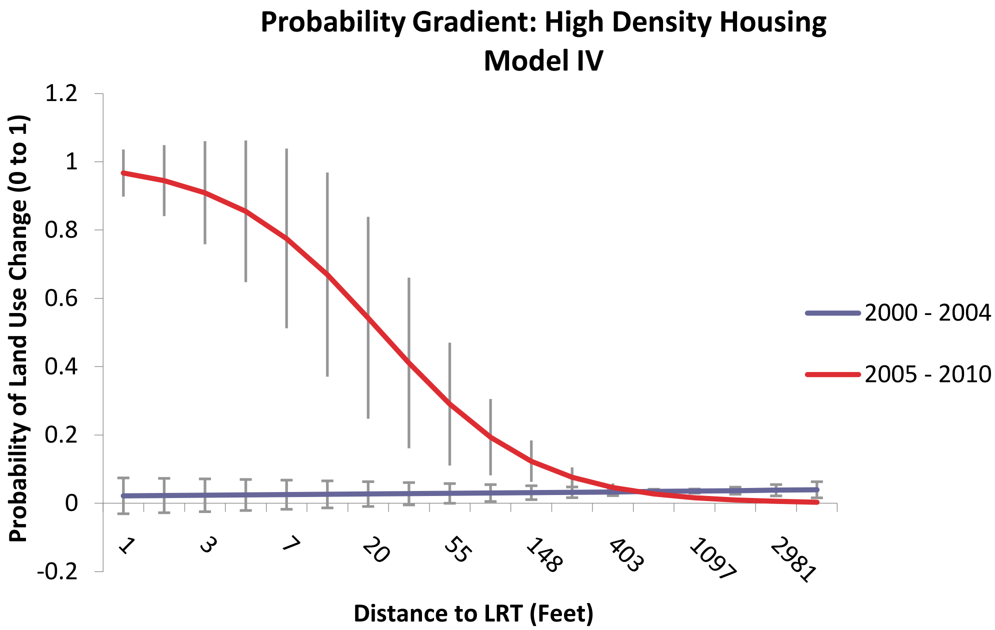


Chart 6.3 High Density Housing

High-density housing was more likely to change land use between 2005 and 2010 than 2000 – 2004. Only seven acres of high-density buildings changed land use during either period, but this graph shows that those buildings that did change use were very close to LRT stations. Like low-density housing, the radius of LRT's effect on land use was very small (limited to about 300 feet from stations).

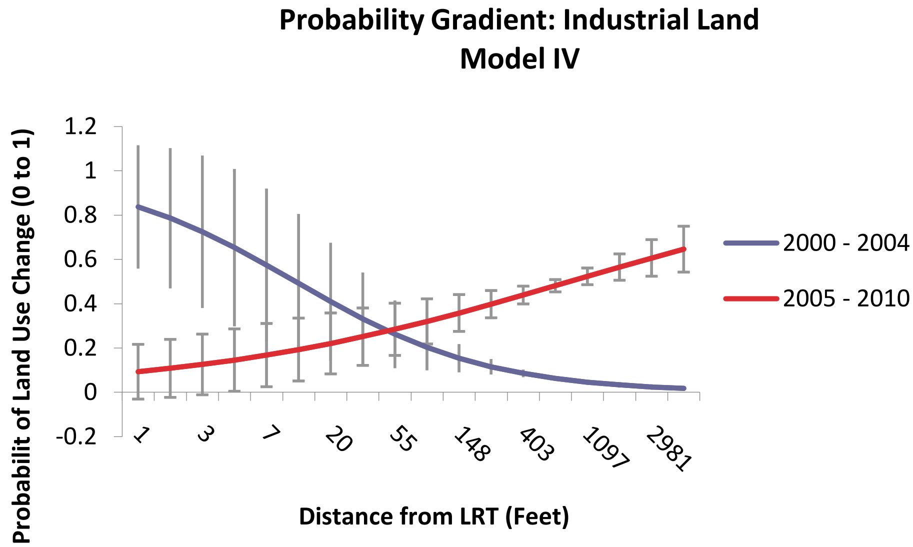


Chart 6.4 Industrial Properties

Before the LRT opened, industrial properties were very likely to change land use, and land use change was responsive to distance from the proposed LRT stations. After the LRT opened, industrial properties still experienced a high level of land use change, but changes were not responsive to distance from stations. 105 of the 135 acres that changed use from 2005 to 2010 converted to commercial land.

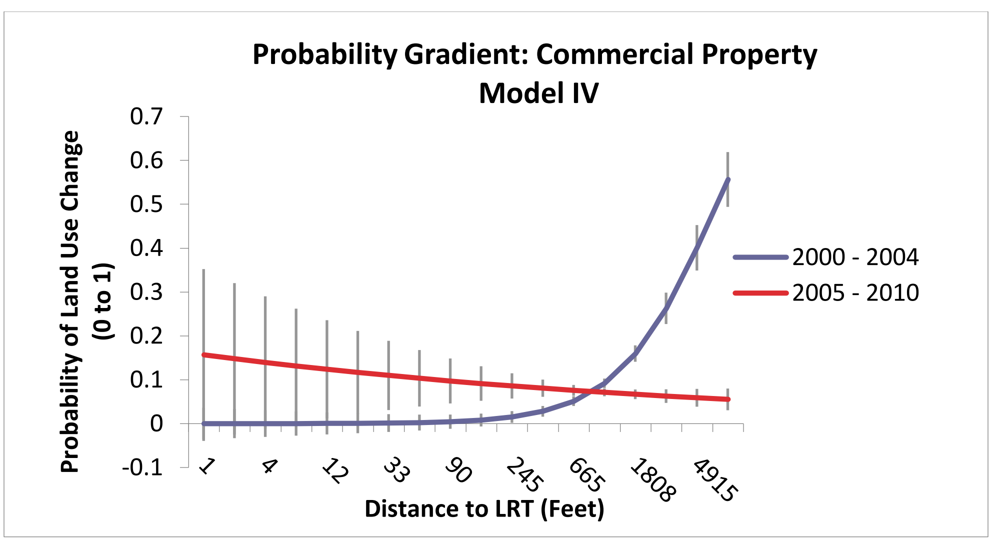
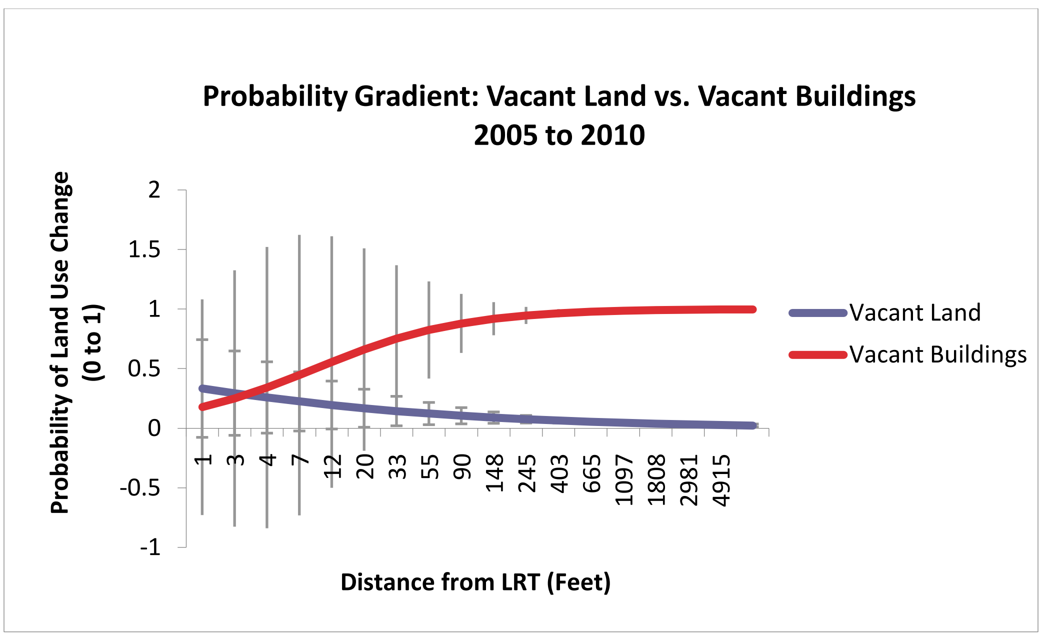


Chart 6.5 Commercial Properties

Before the LRT opened, commercial properties were very unlikely to experience land use change. After the LRT opened, commercial property land use change was more responsive to distance from LRT stations. The radius of LRT's effect was relatively long compared with other uses. The increase in probability from 1000 – 5000 feet in the first period may be the result of an omitted variable bias. From 2000 to 2004, the majority of land use changes were commercial to high-density housing. After 2005, I found 82 of that 145 acres that changed use became vacant land. That shift could indicate properties in the process of redevelopment.

Separating out vacant buildings from the other categories reveals vacant buildings were extremely likely to change land use within the 1-mile submarket, although it is unclear how responsive it is to LRT. This separation is only possible for the 2005 to 2010 period. Below, I compare the probability gradient of vacant buildings to vacant land during that time. We see vacant buildings very likely to experience land use change.



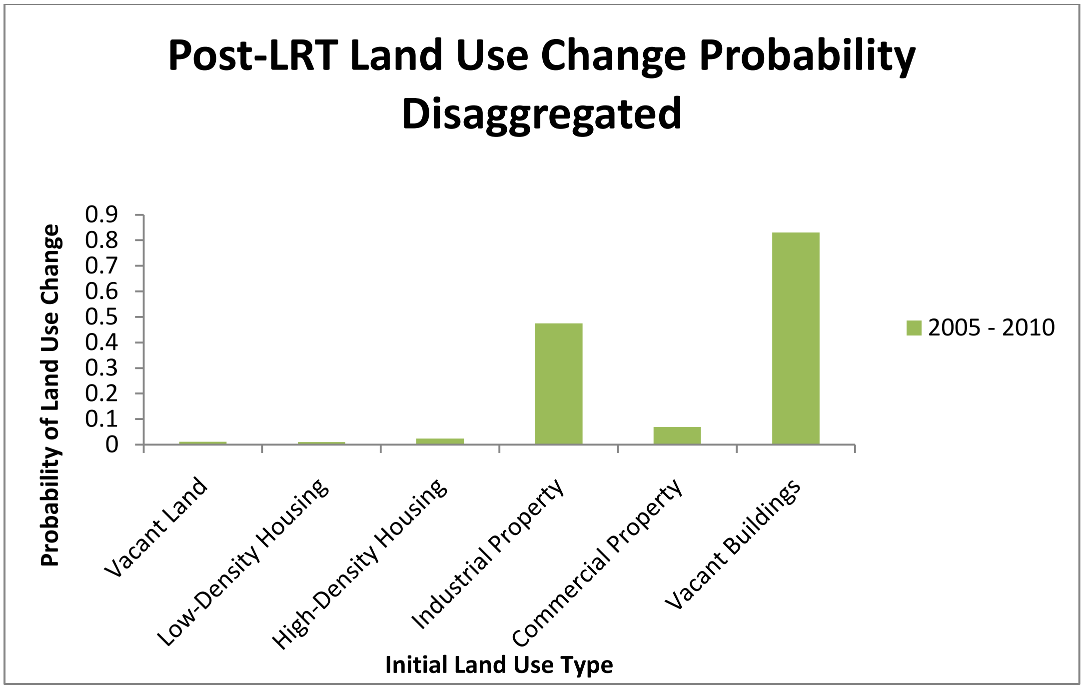


Chart 6.7: Magnitude of marginal effect of land use, disagreggated

Chart 6.7 shows vacant buildings were the most likely to experience land use change, holding all else equal. Industrial properties were the second most likely to experience land use change. In is unclear for both of these types of properties whether or not the change in land use is responsive to LRT.

The results of Model IV confirm that land use determines how a property responds to LRT proximity. I evaluate the reactions based on the magnitude of the probability of land use change near the station and the radius of the effect. Tables 6.5 and 6.6 rank results by magnitude of change directly next to stations, the radius of the effect, and the conditional probability of change across the entire sample area.

Table 6.5: 2000 - 2004 Marginal Magnitude, Radius and Average Conditional Probability			
Land Use Type	Atmeans* Magnitude	Radius (feet)	Average Probability Conditional on other covariates*
Vacant Land	0.98	4915	0.73
Low-Density Housing	0.84	90	0.01
Industrial	0.84	665	0.08
High-Density Housing	0.02	7	0.05
Commercial	0.00	0	0.11

** Atmeans evaluates at the mean value for covariates *Average for the 1-mile area

Table 6.6: 2005 - 2010 Marginal Magnitude, Radius and Average Conditional Probability			
Land Use Type	Atmeans* Magnitude	Radius (feet)	Average Probability Conditional on other covariates*
High-Density Housing	0.97	148	0.03
Low-Density Housing	0.57	55	0.01
Vacant Land	0.34	403	0.06
Commercial	0.15	90	0.08
Industrial	0.09	Not Responsive	0.46

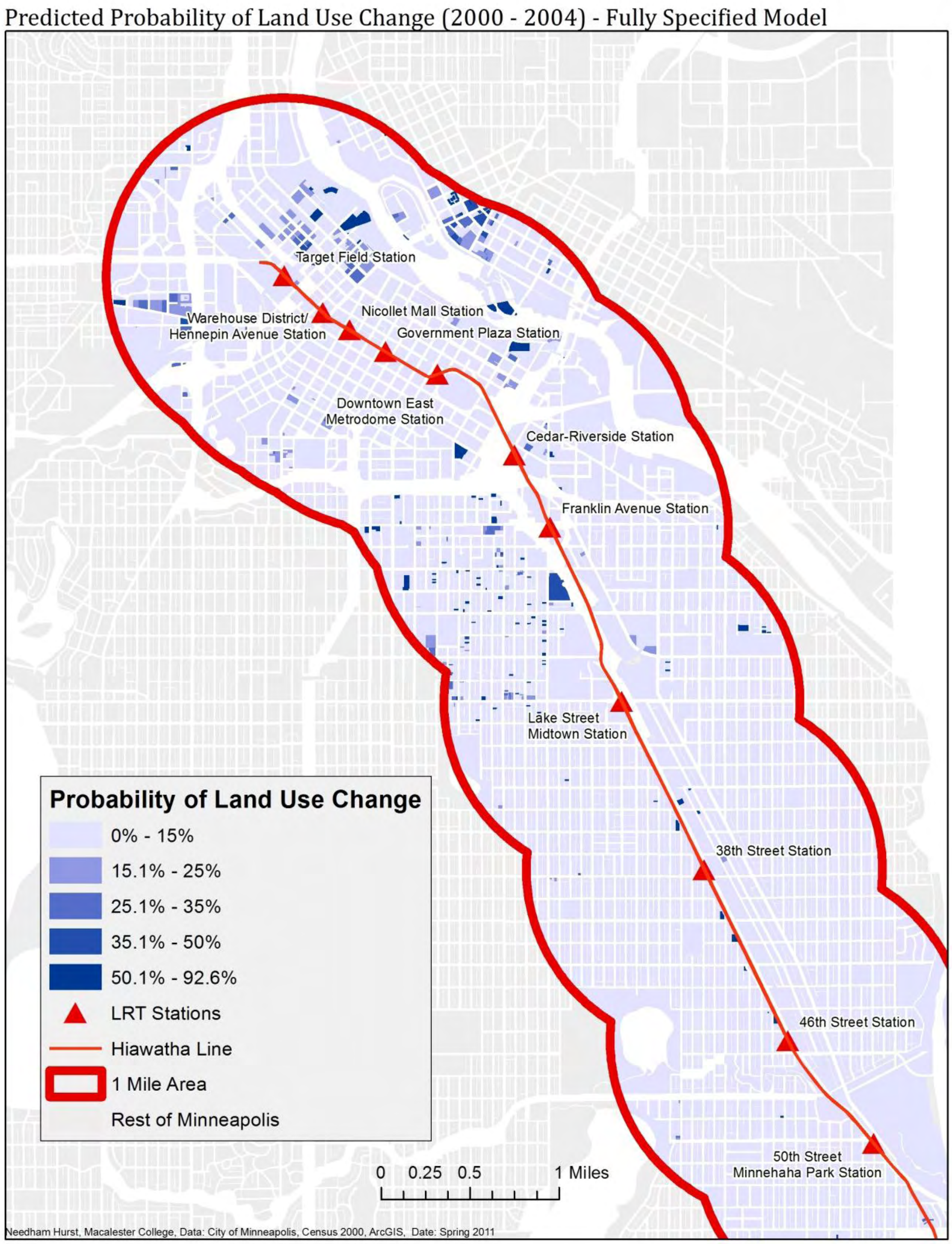
** Atmeans evaluates at the mean value for covariates *Average for the 1-mile area

Vacant land and low-density housing near the LRT tend to be the first types of properties to experience land use change. These properties are cheaper, smaller, and generally easier to convert into other uses. Table 6.5 and 6.6 show that expectations of LRT may have been enough to incentivize land use change on these cheaper properties. Industrial land also shows a high likelihood of change in the first period—perhaps due to the popularity of converting industrial properties into high-density, condo-style apartments and commercial outlets.

For both low- and high-density housing, the effect of the LRT on land use change only reaches 50 to 150 feet from stations. This result is consistent with findings from the literature. The small radius of effect suggests that the marginal effect of LRT on accessibility is limited to the station area directly.

Graphs 6.4 and 6.5 exhibit some interesting results for industrial and commercial properties. Industrial land use change was very high and very responsive to proximity to LRT stations before the Hiawatha line was built. Most of those changes were industrial to commercial conversions. After the line was built, industrial land in the entire 1-mile area was still likely to change land use, controlling for other covariates, but proximity to LRT was not the driving force. These results suggest that expectations of LRT were enough to cause land use changes in industrial land, and after the LRT was built there were some concurrent factors that led to deindustrialization in that area generally. In general, we see industrial properties located in low and middle class neighborhoods experiencing more land use change. Commercial land use change was very unlikely before the LRT was built, but the probability increased to .15 for commercial properties near the LRT after the line was built. Investment to change a commercial property's land use was contingent upon the LRT actually existing; it was not driven by expectations. However, much of the changes that occurred in the second period were conversions to vacant land—which is ambiguous because it could be in the process of redevelopment.

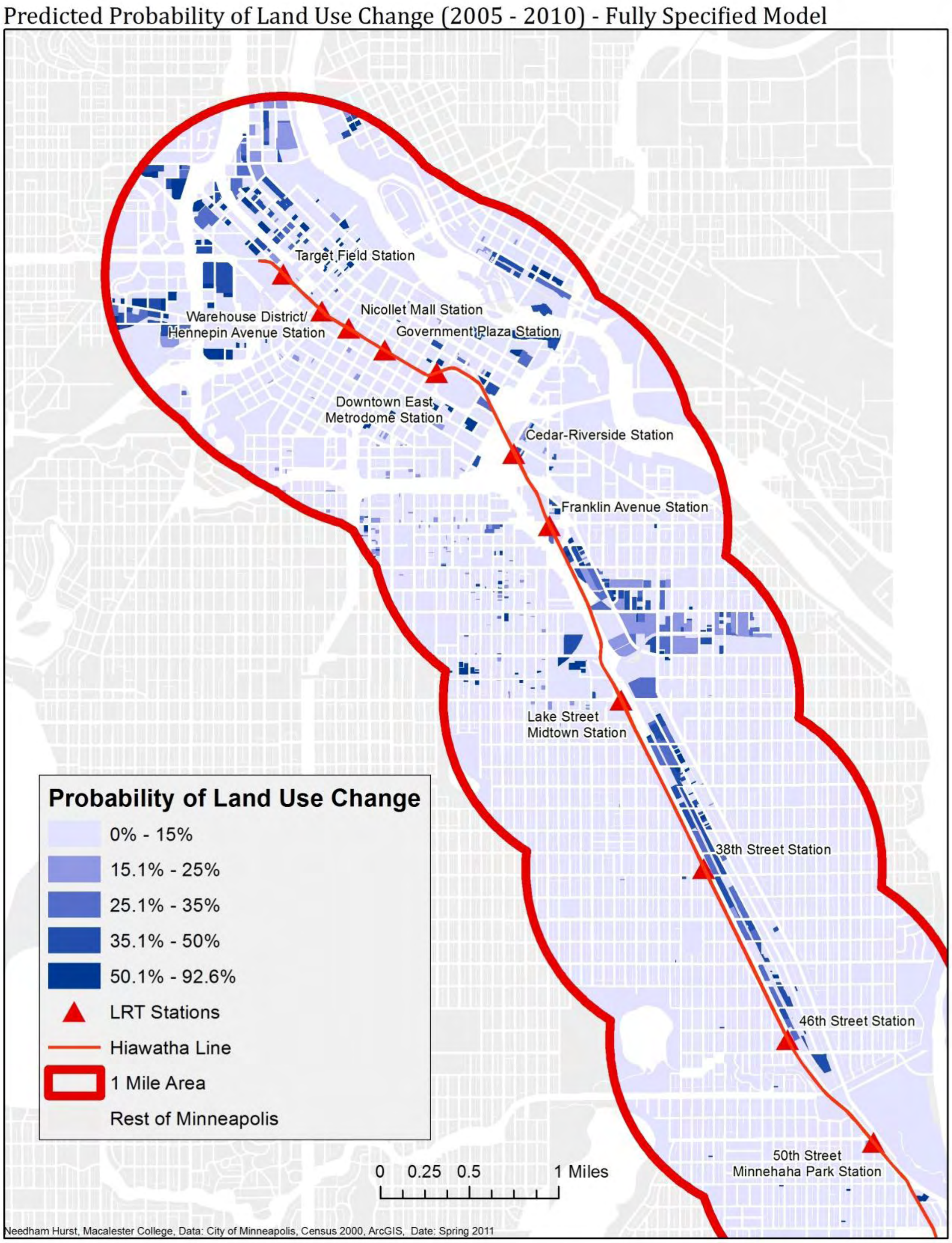
Model V reaffirms these results and adds to the analysis by providing a more explicit geographic perspective. Maps 6.1 and 6.2 show the predicted probability of land use change before and after the Hiawatha Line. Before the line, Map 6.1 shows that there was a slightly higher probability of land use change for properties near the line. The geographic spread of land use change increases as neighborhoods transition from primarily single-family homes in the south to the denser, more diverse land use near the CBD.



Map 6.1 Pre-LRT Land Use Change Probabilities – Predicted land use change was fairly low during this period. We can see some areas near the LRT were likely to experience land use

change, but most changes were predicted to take place in the CBD and between Lake Street and Franklin Avenue stations.

After the Hiawatha Line opened, the probability of land use change increased, especially between the 46th Street and Franklin Avenue stations. Between primarily residential stations (46th to Lake), the probability of land use change was high only along a narrow band near the Hiawatha corridor. Between Lake Street and Franklin Avenue station, the probability of land use change was more widespread, responding to the diversity of land uses and socio-economic conditions in that area. The downtown area just northeast of the Target Field station experienced marked increase in the probability of land use change, perhaps indicating some downtown revitalization discussed in the previous literature.



Map 6.2 Post-LRT Land Use Change Probabilities – Predicted land use change increased, especially between the 46th Street and Franklin Avenue Stations. The

increase narrowly follows the corridor in the south, and spreads out as the LRT goes through neighborhoods with diverse land use.

The models' accuracy can be measured in several ways: McFadden's Pseudo-R^2, Likelihood Ratio Chi-squared, Sensitivity, and Specificity. The pseudo-R^2 gives a very general approximation of the logistic model's fit, and can be interpreted similarly to R^2 from OLS. The likelihood ratio chi-squared determines whether the coefficients on any of the independent variables could equal zero. A high ratio indicates the model is better than the constant only regression. Sensitivity measures the probability of predicting land use change for properties that experienced change. Specificity is the probability of predicting no land use change for properties that did not experience change (Rodriguez 2011).

Table 6.5 shows that Model IV has a probability of correctly predicting 24.3% of land use change that actually occurred in period 1, and 25.7% that occurred in period 2.

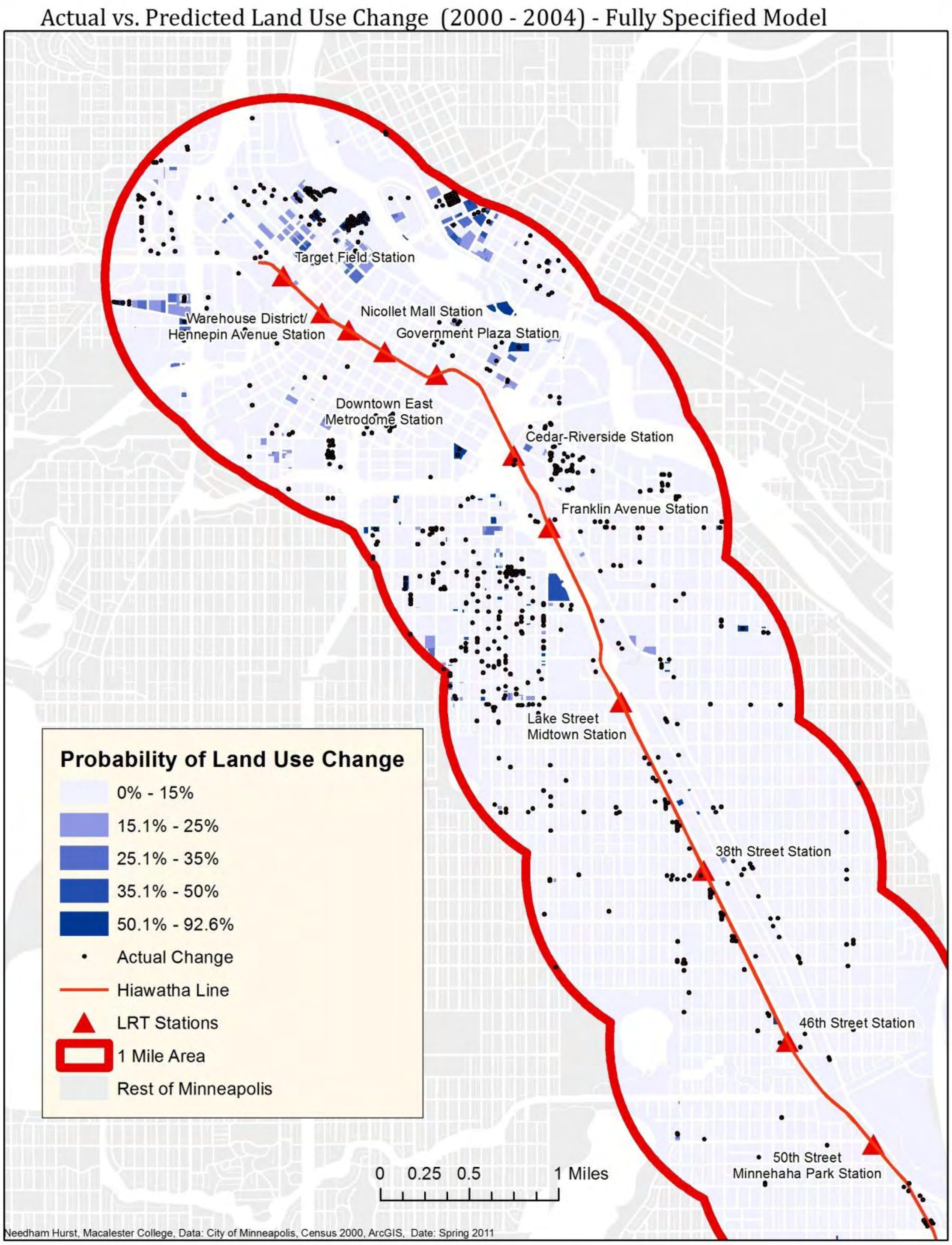
Table 6.5 Logistic Regression Accuracy Models IV & V

	IV		V	
	Period 1	Period 2	Period 1	Period 2
Pseudo-R^2	.3328	0.3553	0.3544	0.3633
LR Chi^2	1579.50	1709.92	1681.98	1747.10
Sensitivity	24.30%	25.74%	32.87%	26.92%
Correct Pos. Pred.	71.76%	64.85%	76.39%	77.67%
N	2117	2117	2117	2117

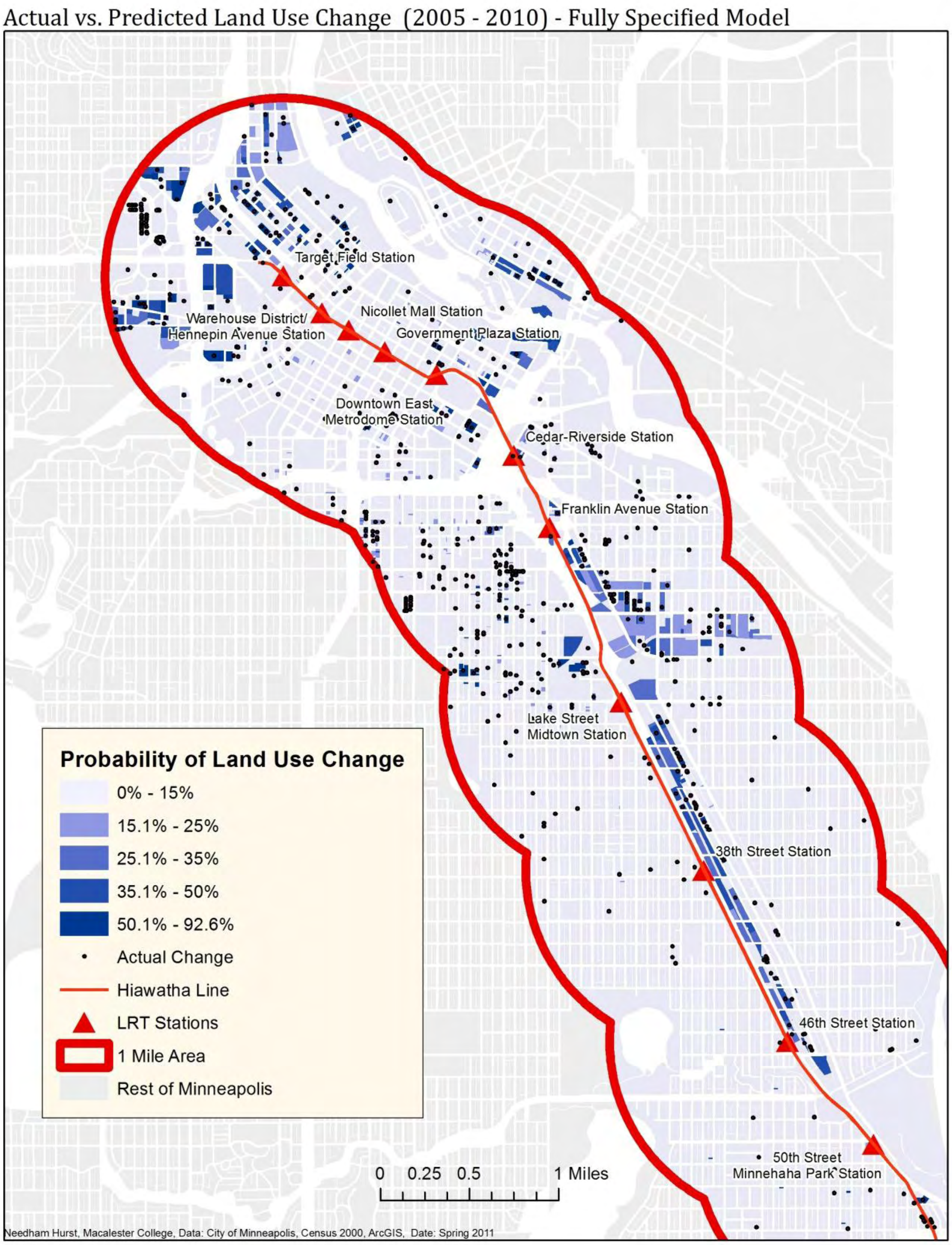
The pseudo-R^2 remains relatively constant across all models, but the likelihood ratio is higher for Model V than Model IV in both periods. It appears that Model VI more correctly predicts land use change that actually occurs. In period 1, it correctly predicted 76% of actual changes and 77% in period 2. I conclude that Model V is only slightly better, but the interaction terms are more theoretically appropriate—making Model V the best estimator of land use change.

Another method to test the models' accuracy is to spatially plot the actual cases of land use change vs. the land use change predicted. From Maps 6.3 and 6.4, we can see that while the model predictions may have not been precise (only exactly predicting less than a third of all changes), the model does capture the general spatial distribution of land use change. Across most of the city, changes took place where the model predicted a density of properties with high probabilities of land use change.

In both 2000 to 2004 and 2005 to 2010, the model tends to underpredict land use change on the west side of the line between the Lake Street/Midway and Cedar-Riverside stations. This area generally corresponds to the Phillips neighborhood, a working-class community that experienced high levels of foreclosure and investment in high-density housing.



Map 6.3 Actual vs. Predicted Land Use Change, 2000 – 2004: Before LRT there was a great deal of land use change near the CBD, and lots of small changes between the 46th and Lake Street stations.



Map 6.4 Actual vs. Predicted Land Use Change, 2005 – 2010: The model still under predicts the intensity of land use change on the west side between Lake Street and Franklin Avenue.

The areas underpredicted by the model occur in both periods, suggesting that the Phillips neighborhood may be systematically more prone to land use change than other neighborhoods. Spatially, the fit of the model appears to be consistent with changes that actually occurred, although there appears to be an underprediction of land use change across the entire area between 2000 and 2004. This period was during the housing boom, so city-wide speculation may have generated land use change that would not have occurred otherwise.

7. Endogeneity

The issue of endogeneity is very important when dealing with the effects of large government interventions like city transit. There are two main problematic causal relationships: 1) the submarket near the LRT is inherently more active and the government chose that location as a result and 2) government interventions like zoning changes may have caused land use change, not LRT itself.

From a policy perspective, a growing area may need LRT more than other areas. Therefore, land use change could be a result of growth in an area rather than response to LRT. Without control variables, the data on the Hiawatha Line show that properties within 1-mile of the LRT were more likely to experience changes than the rest of Minneapolis:

Table 7.1 General Land Use Change Probabilities

	Pre-LRT	Post-LRT
Within 1-mile	.032812***	.0322455***
	(.001176)	(.0011661)
Rest of Minneapolis	0.02161***	.018823 ***
	(0.0005159)	(.0004822)

Table 7.1 shows that for each period, properties within 1-mile of the LRT have about a 3% probability of land use change compared with about 2% in the rest of Minneapolis.

7.1 Trend Divergence

Both before and after LRT, there appears to be more land use change activity within 1-mile of LRT stations than in the rest of Minneapolis. This trend divergence might be causally related to LRT, or it might be an inherent[5] aspect of the submarket along the Hiawatha corridor. To test for "inherent changes", I examine land use change between the two areas controlling for property

[5] I use the word "inherent" here to indicate a property with a particular land use type is more likely to experience land use change simply by being the submarket, holding all other property characteristics, neighborhood, and location covariates constant. An example might be if developers change land use in the area because of expectations or enthusiasm for the submarket not based on measurable variables.

characteristics, land use, neighborhood characteristics, and other location factors using a binary logit model. My findings suggest the submarket within 1-mile of LRT was not inherently more likely to experience land use change after accounting for neighborhood, location, and property covariates.

Below is the model specification for the trend divergence test.

Table 6.1 Model Specification

Models	I
Within 1-Mile Dummy	√
Land Use	√
Land Use * Within 1-Mile	√
Location Controls	√
Neighborhood Controls	√
Property Controls	√

For more details on each variable group, see Table 4.3.

This specification uses all Minneapolis properties (n=96852) except parks, farms, and transportation related parcels (small city-owned right-of-way parcels, etc).

In general, I only find trend divergence of significant magnitude in the 2000 – 2004 period for vacant land. The land uses have significant but very small differences between the 1-mile area and the rest of Minneapolis, evaluating all other covariates at the mean. The results are displayed in the appendix (Table A.3), however I've extracted the marginal probabilities of land use change below to give a sense of magnitude:

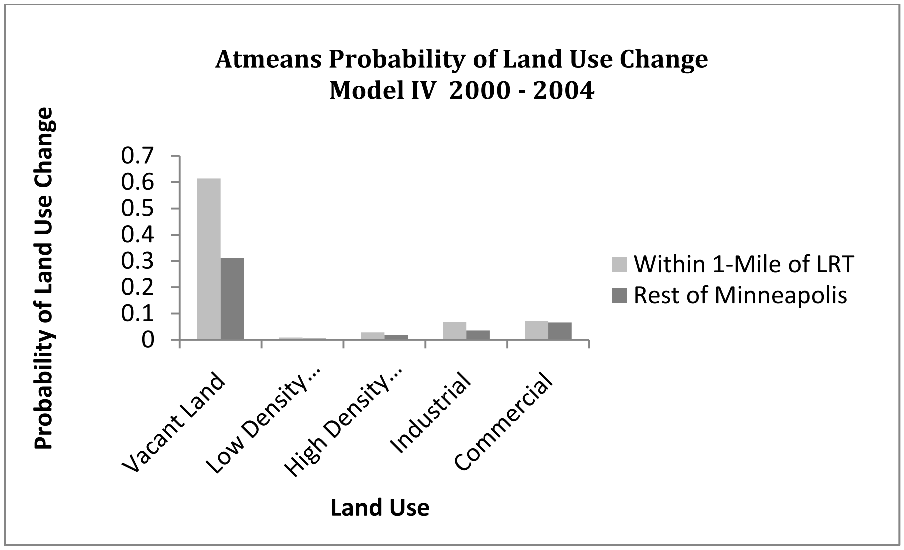


Chart 7.1 – Marginal Probability of Land Use Change, 2000 – 2004

The chart above shows the probability of land use change for different land use evaluated at the mean value for other covariates. It suggests that vacant land was more likely to experience land use change if it was within 1-mile of the LRT, holding all else equal. This supports evidence that vacant land in the southeast corridor submarket was inherently more likely to experience change.

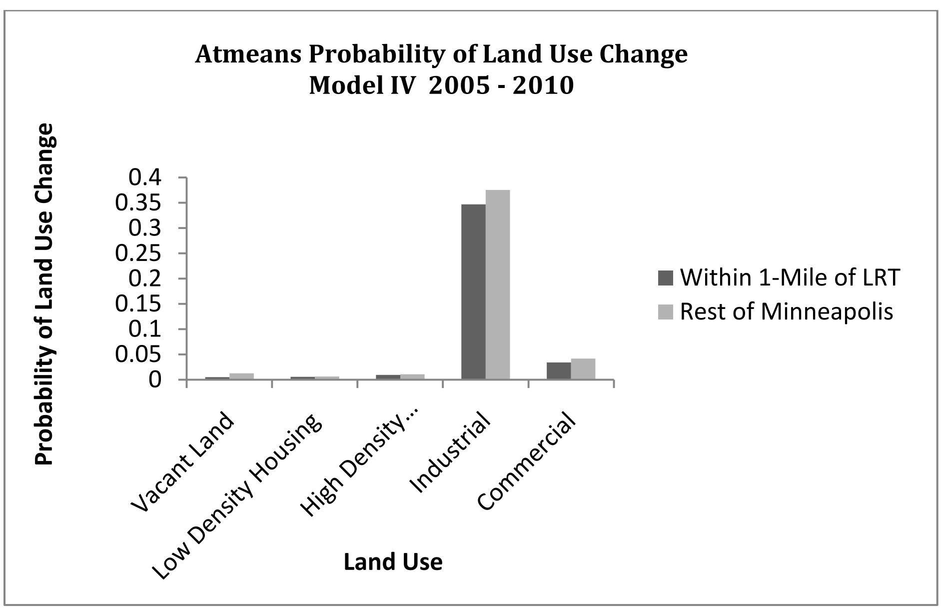


Chart 7.2 – Marginal Probability of Land Use Change 2005 – 2010

The results in Chart 7.2 show that the probability land use change on an average industrial property in an average neighborhood was no greater in the submarket than in the rest of Minneapolis. Therefore, this result supports the idea that properties of specific a land use in the submarket was not *inherently* more susceptible to change, after accounting for the neighborhood, property, and location covariates. But, as we discussed before, the area around the LRT is extremely diverse and includes neighborhoods of a variety of income classes and racial make-up. If we look at the average predicted probability of land use change for different land uses conditional on other covariates (rather than at the mean), we do see trend divergence.

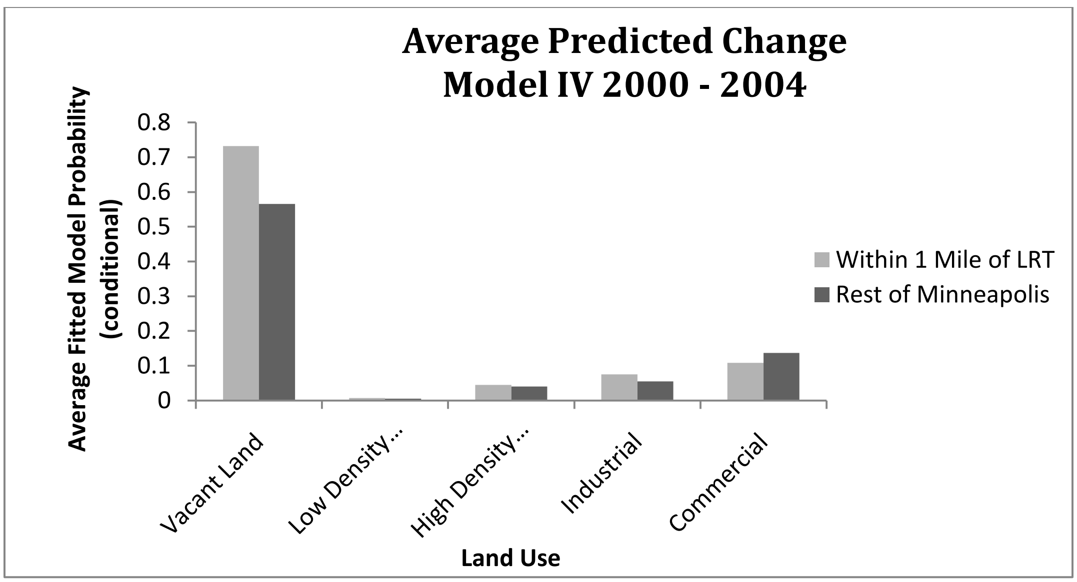


Chart 7.3 Averaged Predicted Change by Type 2000 – 2004

When evaluating the average predicted probability of change conditional on all other covariates, I do find divergence occurring at greater magnitudes when comparing the area within 1-mile of LRT and the rest of Minneapolis. In 2000 – 2004, vacant land was almost 20% more likely to experience change near LRT and industrial land was 3% more likely to experience change.

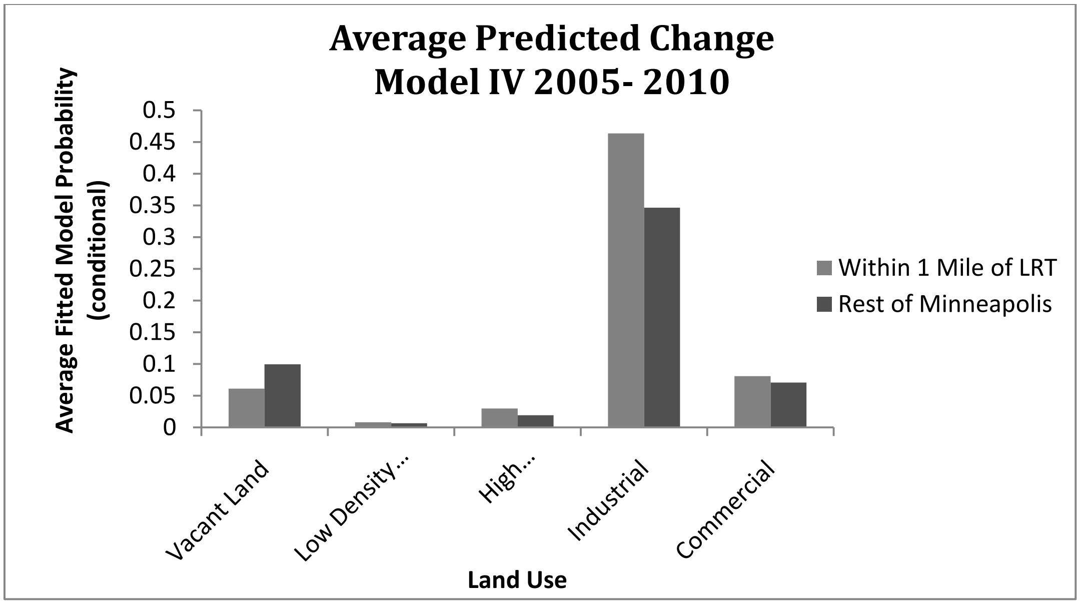


Chart 7.4: Average Predicted Change by Type 2005 – 2010

In contrast with Chart 7.2, which used an at-means evaluation, when evaluating land use change trends conditional on other covariates, I find industrial land is 10% more likely to undergo land use change if it is within 1-mile of LRT. This finding suggests that being "industrial" alone is not enough to induce more change near LRT, but that the combination of industrial land with covariates from the area near LRT (mostly middle and lower-income neighborhoods) does induce more change than we see in the rest of Minneapolis.

Overall, this trend analysis suggests the properties within 1-mile of LRT were no more likely to experience land use change than properties in the rest of Minneapolis, except vacant land in the pre-LRT period. In other words, an industrial property in the LRT submarket was no more likely to experience land use change after accounting for the type of neighborhood, the property characteristics and the location of the industrial property. The divergence for vacant land indicates that expectations of LRT were enough to cause divergent trends for vacant properties, regardless of covariate controls.

The primary driver of the diverging land use trends appears to be a result a combination of neighborhood covariates like income, how a property use matches surrounding uses, the proximity to downtown, the age of neighborhood buildings, the population density and the neighborhoods education levels. Table A.3 provides the results in detail.

If causality exists, I would find not only that land use change is responsive to distance to stations within the 1-mile radius, but also there would be an increase in the probability of land use change after LRT opened. The charts and maps in section 6 definitely find statistically significant differences in the magnitude of LRT's effect on land use change between the two periods. Table 7.2 below illustrates that if I do not control for location, neighborhood, and property factors, the results are not statistically different between the two models and omitted variables change the direction of these effects:

Table 7.2 Logistic Regression Results: Models I - IV

	I		II		III	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Ln(DistLRT)	-0.337***	-0.446***	-0.701***	0.982***	0.301	0.833***
	(0.0670)	(0.0666)	(0.191)	(0.179)	(0.337)	(0.265)
Low Den. Housing			-5.726***	8.258***	1.093	8.204***
			(1.618)	(1.559)	(2.462)	(2.100)
High Den. Housing			-5.821***	9.365***	-2.007	11.65***
			(2.039)	(2.242)	(3.124)	(2.656)
Industrial			-7.659***	7.981***	-0.895	7.405***
			(1.841)	(1.540)	(2.685)	(2.090)
Commercial			-13.61***	5.181***	-8.614***	10.02***
			(1.652)	(1.573)	(2.580)	(2.128)
LDH*Ln(DistLRT)			0.144	-1.616***	-1.002***	-1.306***
			(0.240)	(0.231)	(0.371)	(0.310)
HDH*Ln(DistLRT)			0.440	-1.592***	-0.294	-1.668***
			(0.302)	(0.333)	(0.464)	(0.392)
Industrial*Ln(DistLRT)			0.765***	-0.899***	-0.363	-0.424
			(0.277)	(0.230)	(0.408)	(0.310)
Commercial*Ln(DistLRT)			1.678***	-0.832***	0.842**	-1.236***
			(0.244)	(0.234)	(0.386)	(0.314)
Rezoned						-0.152
						(0.196)
NON-MAJ USE (00 or 05)					0.316**	0.902***

					(0.128)	(0.130)
ACRES (00 or 05)					-0.0447	0.148**
					(0.104)	(0.0748)
MixedUseNeighborhood (00 or 05)					-0.0402	-0.667***
					(0.0434)	(0.0483)
Ln(EMV) (00 or 05)					1.147***	2.135***
					(0.400)	(0.286)
	-1.146**	-0.493	4.841***	-8.675***	-0.804	-2.033
Constant	(0.449)	(0.444)	(1.292)	(1.216)	(2.290)	(1.862)
Pseudo-R^2	.011	0.0051	.2253	0.2718	0.2397	0.2758
LR Chi^2	19.14	33.34	1493.38	1777.10	1588.76	1803.24
Sensitivity	0%	0%	0.00%	0	3.85%	0
Specificity	100%	100%	100.00%	100	99.84%	100
N	22949	22949	22949	22949	22949	22949

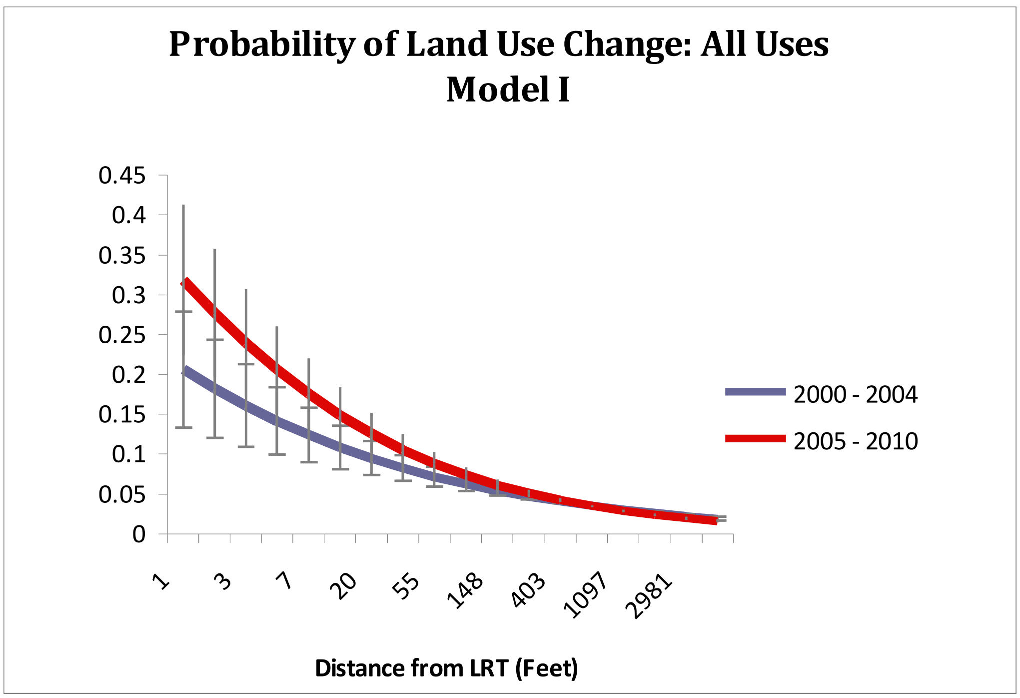


Chart 7.1 Model I Predictions: Without control variables, the effect of LRT on land use change is not statistically different between the two periods.

The models with only proximity to LRT and land use variables correctly predict 0% of the properties that changed land use. This error occurs because the variables do not generate high enough probability of change (above .5) to indicate a change in use. Only after I factor in covariates like neighborhood, property and location characteristics does the model predict land use change will happen (see section 6.1). This result supports the notion in the literature that light rail alone is not enough to induce land use change.

Endogeneity problem #1—did inherent land market activity or LRT cause land use change—appears to be taken care of in this analysis. I conclude that LRT does have an effect, but for most properties the radius of effect is limited to the area directly around station areas. I have no way of addressing the question of whether the government chose the alignment of the LRT because it perceived that land market to be more active. The Hiawatha Corridor is the only feasible north-south corridor for LRT in Minneapolis.

7.2 Zoning

Endogeneity problem #2—did rezoning or LRT cause land use change—is much trickier to resolve. Vessali explains that LRT investment creates zoning changes that promote denser land use, so while zoning may appear to be the primary factor inducing land use change, zoning would not have happened if the LRT was not built (1996). While this assertion is true in the case of the Hiawatha Line, the question of price-driven land use change vs. zoning-driven land use change is still unanswered.

Models IV and IVcontrol for zoning changes, but all of the rezoning efforts were around station areas. The spatial multicollinearity of zoning changes and proximity to LRT prevents us from seeing outright whether or not rezoning was important. The way rezoning studies were implemented, however, provides a quasi-natural experiment. The zoning study areas are well mapped and have definite boundaries. There were also a few stations downtown and the 50th Street Station that had not undergone rezoning studies at the time of this research.

Table 7.3 Land Use Change within 1000 Feet of Stations
2005 - 2010 - Properties

	Changed Use	No Change	Percentage Changed
Inside Rezoning Area	60	610	8.96%
Outside Rezoning Area	396	11,449	3.34%

Units = number of properties

Using this clear boundary and inconsistent application, I compare land use change for those properties equally proximate to LRT that were not in rezoning areas vs. those properties that were in rezoning areas. Table 7.3 summarizes the percentage of properties that experienced land use change in rezoning study areas within 1000 feet of stations vs. those properties within 1000 feet that were not in rezoning study areas. It appears 9% of properties in rezoning areas changed land use vs. 3.3% of properties not in rezoning areas.

Examining the data directly, it appears rezoning had a large effect on land use change. After controlling for property, neighborhood and location covariates (no interactions), I find a 5.5% probability of change for properties inside rezoning areas vs. a 3% probability of change for properties outside rezoning areas. The rezoning effect is statistically different from the effect of LRT without rezoning (chi^2 = 11.09).

Table 7.4 Rezoning's Effect with Controls
2005 - 2010 - Properties within 1000 Feet of Stations

	Probability of Change
Inside Rezoning Area	0.0554635
	(0.0016178)
	0.0305546
Outside Rezoning Area	(0.0016178)

Units = marginal effects. Controls: property, neighborhood, location covariates

Rezoning did have an effect on land use change. I would like to note, however, that land use change that occurred in expectation of the Hiawatha Line is not related to rezoning efforts. The zoning changes did not take effect until after the line was completed. There is also a major political economy aspect of rezoning that would be a fruitful area of new research. The rezoning study areas near residential stations in south Minneapolis were much smaller than those in more transitional neighborhoods near the Lake Street and Franklin Avenue stations. The strength of neighborhood associations and politics of neighborhood policymaking should be looked at more closely in future research.

8. Conclusion

I use a binomial logistic regression to measure the effect of distance to the Hiawatha Line light rail transit stations on land use change in Minneapolis from 2000 to 2010. First, I examined the causes for the diverging land use trends between the rest of Minneapolis and the area within 1-mile of LRT. The concentration of working class neighborhoods, mixed-land use areas, older, denser development within 1-mile of LRT appears to explain the diverging trends more than developer preferences about types of land use for redevelopment. Existing land use near stations becomes important when examining both the magnitude and the radius of the land use change effect within the 1-mile submarket.

Second, I examined the radius of LRT's effect on land use. The findings in section 6.1 show the radius is limited, especially in areas dominated by low-density housing, high-density housing and commercial property. I looked within the 1-mile area near LRT and estimated the radius using a logit regression. The two best models (IV and V) show the Hiawatha Line's effect on low-density housing land use change extends only out to 90 feet from stations. Vacant land experienced the highest magnitude and radius of LRT's effect. Vacant land was the first type of property to be converted to denser uses—indicating the Hiawatha Line increased the marginal accessibility of properties enough to generate higher housing demand, high prices, and which in turn incentivized development on vacant properties. Industrial properties within 1-mile of stations were 10% more likely to experience land use change from 2005 to 2010 than industrial properties in the rest of Minneapolis. This finding is complicated by the fact that industrial properties did not change land use responsive to distance from LRT. I conclude industrial properties experienced more land use change near LRT mostly because of compounding neighborhood and location variables, although deindustrialization appears to be a major citywide trend from 2005 to 2010.

The policy implications of this paper are important as city planners decide on alignment and cost-benefit of LRT investments. The findings suggest that the effect of LRT is limited in wealthy, low-density neighborhoods. LRT does have a strong effect on vacant properties and encourages urban infill. Area with mixed-use land use patterns, higher population density, lower-income residents and older structures experienced the most land use change because of LRT. Proximity to the central business district also had a strong effect on probability of change. Complementary policies like rezoning had a small but significant positive effect on land use change, although the political economy of rezonings and neighborhood opposition needs to be studied further.

Comparing the predicted land use change maps with socio-demographic maps, there is clear spatial correlation between low-income, minority neighborhoods and high probabilities of land use change. Along the corridor between 50th Street and Lake Street, the radius of LRT's effect is smallest—following the corridor closely (Map 6.2). As we move toward downtown Minneapolis, the spread of land use change is greater—although it cannot be fully attributed to the presence of LRT. There is a correlation between the existing dominant use of the neighborhood and land use change—with mid-town and downtown mixed use areas more likely to experience changes.

There are several directions for next steps in this analysis process. It would prove useful to combine a hedonic model's price effect estimates with land use changes at the property level. This would be an intensive process, but would allow us to see the price elasticity of land use change, a statistic that would prove useful as policymakers think about creating denser, more walkable communities. This research does not look directly at displacement of residents because of price increases, an important topic that is often difficult to study. Finally, the political economy of large transit investments cannot be ignored. This paper approached land use change primarily from a market-based perspective, and a fuller study could examine the city-neighborhood politics of land use zoning and change.

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Appendix

Table A.1 Land Use Categorization

General Category	Parcel Data Classification	General Survey Classification
Vacant, Undeveloped, No Building (1)	Vacant Land – Apartment (w/o building) Vacant Land – Industrial (w/o building) Vacant Land – Commercial (w/o building) Vacant Land – Residential (w/o building) Common Area (No Value)	Undeveloped (210)
Low Density Housing (2)	Residential Residential - Miscellaneous/Garage Residential - Zero Lot Line Disabled Blind Blind Joint Tenancy Seasonal - Residential Rec Triplex Disabled Joint Tenancy Double Bungalow Vacant Land – Residential (w building)	Seasonal/Vacation (112) Single Family Detached (113) Single Family Attached (114) Manufactured Housing Parks (116)
High Density Housing (3)	Apartment Apartment Condominium Cooperative Housing - Low Income < 4 units Housing - Low Income > 3 units Townhouse Vacant Land – Apartment (w building)	Multifamily (115) Mixed Use Residential (141)
Industrial (4)	Railroad Utility Industrial Vacant Land – Industrial (w building)	Industrial and Utility (151) Mixed Use Industrial (142) Major Highway (201) Railway (202)
Commercial (5)	Commercial Commercial Telelphone Vacant Land – Commercial (w	Retail or Other Commercial (120) Office (130)

	building)	
	Social Club	Mixed Use Commercial and Other (143)
	Non-Profit Community Assoc.	Institutional (160)

Table A.2 Logistic Regression Results: Models IV & V

	V		IV	
Dependent: Land Use Change	Period 1	Period 2	Period 1	Period 2
Ln(DistLRT)	-51.77**	73.71***	5.579***	4.566**
	(25.04)	(26.04)	(1.907)	(1.976)
Low Den. Housing	1.113	1.854	-2.699	-1.468
	(3.158)	(2.951)	(2.819)	(2.330)
High Den. Housing	-9.145**	8.747***	-6.357*	4.831*
	(3.829)	(3.322)	(3.512)	(2.744)
Industrial	-1.782	3.887	-2.789	0.307
	(3.527)	(3.085)	(3.137)	(2.151)
Commercial	-9.538***	3.427	-12.50***	0.526
	(3.224)	(2.933)	(3.028)	(2.223)
LDH*Ln(DistLRT)	-0.909*	-0.226	-0.338	0.309
	(0.474)	(0.448)	(0.423)	(0.353)
HDH*Ln(DistLRT)	0.743	-1.157**	0.371	-0.542
	(0.567)	(0.503)	(0.521)	(0.414)
Industrial*Ln(DistLRT)	-0.299	0.216	-0.133	0.767**
	(0.534)	(0.475)	(0.477)	(0.332)
Commercial*Ln(DistLRT)	0.956**	-0.155	1.425***	0.312
	(0.481)	(0.448)	(0.451)	(0.339)
Rezoned		0.313		0.172
		(0.248)		(0.236)
NON-MAJ USE (00 or 05)	4.700***	-1.965	0.551***	0.602***
	(1.666)	(1.551)	(0.131)	(0.129)
ACRES (00 or 05)	-0.383	2.645***	-0.0828	0.131*
	(1.498)	(0.857)	(0.113)	(0.0748)
MixedUseNeighborhood (00 or 05)	2.171***	-2.054***	-0.0601	-0.653***
	(0.675)	(0.663)	(0.0458)	(0.0513)
Ln(EMV) (00 or 05)	20.92	-5.992	0.658	1.524***

	(17.38)	(4.120)	(0.453)	(0.307)
Ln(POP_DENSITY00)	4.542**	2.067	2.544**	0.0594
	(1.863)	(1.521)	(1.222)	(0.108)
Ln(DistCBD)	0.466	2.547*	-1.080	2.553***
	(1.160)	(1.493)	(1.041)	(0.972)
Ln(DistHWY)	6.098***	1.069	4.118***	2.162**
	(1.291)	(1.030)	(1.200)	(0.920)
Ln(DistPark)	0.329	-0.213	0.134*	-0.738
	(1.317)	(0.945)	(0.0706)	(0.822)
Ln(DistLake)	1.832	0.884	-0.365***	-0.0630
	(1.394)	(1.227)	(0.0891)	(0.797)
MED_Yr_BUILT	-0.188**	0.186**	0.0148***	0.00635
	(0.0791)	(0.0769)	(0.00466)	(0.00558)
Ln(MEDINCOME)	-9.463**	10.34***	0.383	-0.0770
	(4.069)	(3.791)	(0.255)	(0.275)
PER_BLACK	-0.0497	-0.0169	-0.0386***	-0.0242
	(0.360)	(0.398)	(0.0106)	(0.0235)
PER_WHITE	-0.119	-0.151	-0.0275***	-0.0123
	(0.312)	(0.345)	(0.00841)	(0.0213)
PER_HISP	-0.350	0.144	-0.0107	0.00532
	(0.266)	(0.265)	(0.0112)	(0.0159)
PER_ASIAN	0.423	0.0786	0.0266*	-0.0162
	(0.374)	(0.387)	(0.0143)	(0.0256)
PER_VACANT	-0.557**	0.0191	-0.0150	0.0103
	(0.268)	(0.244)	(0.0153)	(0.0164)
PER_COLLEGE	0.682***	0.226	-0.0255*	-0.00746
	(0.208)	(0.171)	(0.0143)	(0.0146)
PER_NATIVE	1.325***	0.251	-0.494***	0.0122
	(0.340)	(0.329)	(0.185)	(0.0196)
Ln(DistCBD)*Ln(DistLRT)	-0.816***	-0.0392	0.198	-0.510***
	(0.280)	(0.0494)	(0.153)	(0.152)
Ln(DistHWY)*Ln(DistLRT)	-0.0374	-0.0349	-0.575***	-0.317**
	(0.170)	(0.0263)	(0.174)	(0.136)
Ln(DistPark)*Ln(DistLRT)	-0.863***	-0.00387	-0.575***	0.120
	(0.187)	(0.0589)	(0.174)	(0.122)
Ln(DistLake)*Ln(DistLRT)	-0.0465	0.0175	.1636295	0.00808
	(0.191)	(0.0514)	(.1143956)	(0.117)
PER_NATIVE*Ln(DistLRT)	-0.192***	-0.0226		
	(0.0507)	(0.0395)		

PER_COLLEGE*Ln(DistLRT)	-0.108*** (0.0315)	-0.0177 (0.0571)		
PER_BLACK*Ln(DistLRT)	0.0121 (0.0530)	0.000579 (0.0371)		
PER_WHITE*Ln(DistLRT)	0.0242 (0.0462)	-0.498** (0.227)		
PER_HISP*Ln(DistLRT)	0.0570 (0.0394)	-0.142 (0.153)		
PER_ASIAN*Ln(DistLRT)	-0.0488 (0.0549)	0.0458 (0.140)		
PER_VACANT*Ln(DistLRT)	0.0816** (0.0406)	-0.123 (0.178)		
Ln(MEDINCOME)*Ln(DistLRT)	1.463** (0.594)	-1.547*** (0.559)		
Ln(POP_DENSITY00)*Ln(DistLRT)	-0.336 (0.208)	-0.290 (0.228)		
NON-MAJ USE (00 or 05)*Ln(DistLRT)	-0.597** (0.248)	0.385* (0.234)		
ACRES (00 or 05)*Ln(DistLRT)	0.0317 (0.227)	-0.388*** (0.132)		
Ln(EMV) (00 or 05)*Ln(DistLRT)	-0.328*** (0.100)	0.219** (0.102)		
MED_Yr_BUILT*Ln(DistLRT)	0.0285** (0.0116)	-0.0270** (0.0115)		
MixedUseNeighborhood*Ln(DistLRT)	-3.164 (2.705)	1.114* (0.598)		
CONSTANT	342.8** (170.6)	-494.8*** (175.6)	-61.01*** (16.90)	-32.51* (19.14)
Pseudo-R2	0.3544	0.3918	0.3328	0.3859
LR Chi2	1681.93	1999.73	1579.49	1969.54
Correctly Predicted	32.87%	31.51%	24.30%	30.42%
Correctly Predicted of Coverted Properties	76.39%	76.21%	71.76%	71.67%
N	21117	21117	21117	21117
Standard errors in parentheses	*** p<0.01, ** p<0.05, * p<0.1			

Table A.3 Trend Divergence Analysis	Trend Divergence	
Dependent: Land Use Change	Period 1	Period 2
Within 1-Mile	0.828*** (0.211)	-0.956*** (0.191)
Low Den. Housing	-4.533*** (0.125)	-0.729*** (0.142)
High Den. Housing	-3.154*** (0.149)	-0.135 (0.183)
Industrial	-2.448*** (0.184)	3.882*** (0.182)
Commercial	-1.829*** (0.120)	1.260*** (0.163)
LDH*Within 1-Mile	-0.535** (0.229)	0.842*** (0.209)
HDH*Within 1-Mile	-0.933*** (0.277)	0.791*** (0.275)
Industrial*Within 1-Mile	-0.636** (0.298)	0.838*** (0.234)
Commercial*Within 1-Mile	-1.300*** (0.237)	0.688*** (0.242)
Rezoned		0.224 (0.198)
NON-MAJ USE (00 or 05)	0.759*** (0.0724)	0.681*** (0.0701)
ACRES (00 or 05)	-0.0655 (0.0497)	0.0120 (0.0193)
MixedUseNeighborhood (00 or 05)	-0.0708*** (0.0270)	-0.484*** (0.0332)
Ln(EMV) (00 or 05)	1.139*** (0.193)	0.741*** (0.189)
Ln(POP_DENSITY00)	-0.439*** (0.0699)	0.181*** (0.0490)
Ln(DistCBD)	0.121*** (0.0364)	-0.571*** (0.0767)
Ln(DistHWY)	0.157*** (0.0395)	-0.0785** (0.0354)
Ln(DistPark)	0.0183 (0.0341)	0.00549 (0.0389)
Ln(DistLake)	0.167*** (0.0489)	-0.0586 (0.0364)
MED_Yr_BUILT	0.0122*** (0.00286)	0.00819** (0.00320)
Ln(MEDINCOME)	0.140 (0.114)	0.214* (0.115)
PER_BLACK	0.0130 (0.0149)	-0.0241* (0.0135)
PER_WHITE	0.0186 (0.0142)	-0.0251* (0.0129)
PER_HISP	0.0207* (0.0107)	-0.0267*** (0.0101)

PER_ASIAN	0.0327** (0.0156)	-0.0159 (0.0141)
PER_VACANT	0.0264*** (0.00890)	0.0496*** (0.00962)
PER_COLLEGE	- 0.0154*** (0.00523)	- 0.0245*** (0.00584)
PER_NATIVE	0.0313** (0.0145)	0.00517 (0.0126)
Constant	-26.53*** (6.186)	-9.942 (6.950)
Pseudo-R2	0.3158	0.2646
Likelihood Ratio	5438	4175.77
Sensitivity	25.57	12.71
Correctly Predicted Change of Actual Change	64.6	61.32
N	96,852	96,852