Modeling Urban Growth in California's Central Valley: A Neoclassic Economic Approach

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GIS technology is growing fast. I am glad to see the GIS data availability is making good progress supported by different organizations nationwide and state wide in California. And improvement of internet technology made the large GIS data set available to everybody who is interested in GIS research at no cost. The availability of GIS data is critical for the revival of geographic study. The America's GIS data management scheme is a good example for China's GIS society. China's fast economic growth and urbanization call for the increasing availability of GIS data on China to all the geographers in China and the world to manipulate the GIS research.

ABSTRACT

Population growth and improved transportation systems caused rapid urban expansion in California's Central Valley in the past century. California's population growth is expected to continue in future decades. Urban expansion causes concerns from several interest groups with different perspectives, including municipalities, counties, land use planning agencies, farmland protection organizations, land developers, and environmental preservation activists. Census population, housing cost, and employment data were collected at census block group and tract levels. Alonso's household general equilibrium theory is employed to explain the population density and housing cost density patterns and their evolution over time. Multivariable and Lowry models are applied to simulate the patterns of urban growth. The relationship between agricultural land value and urban fringe population density is found. The Neoclassic economic explanation for urban growth in the study area is largely confirmed. A forecast for the Central Valley area's urban expansion is constructed by manipulating land use data from US Geological Survey, California Department of Water Resources, and Farmland Monitoring and Management Program. Neoclassic economic principles are employed to probe a way of efficient urban growth through case study of the major urbanized areas in the Central Valley.

Key Words: Central Valley, Household General Equilibrium Theory, Urban Expansion Models, Land Use Conversion Forecast

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CHAPTER 1

INTRODUCTION

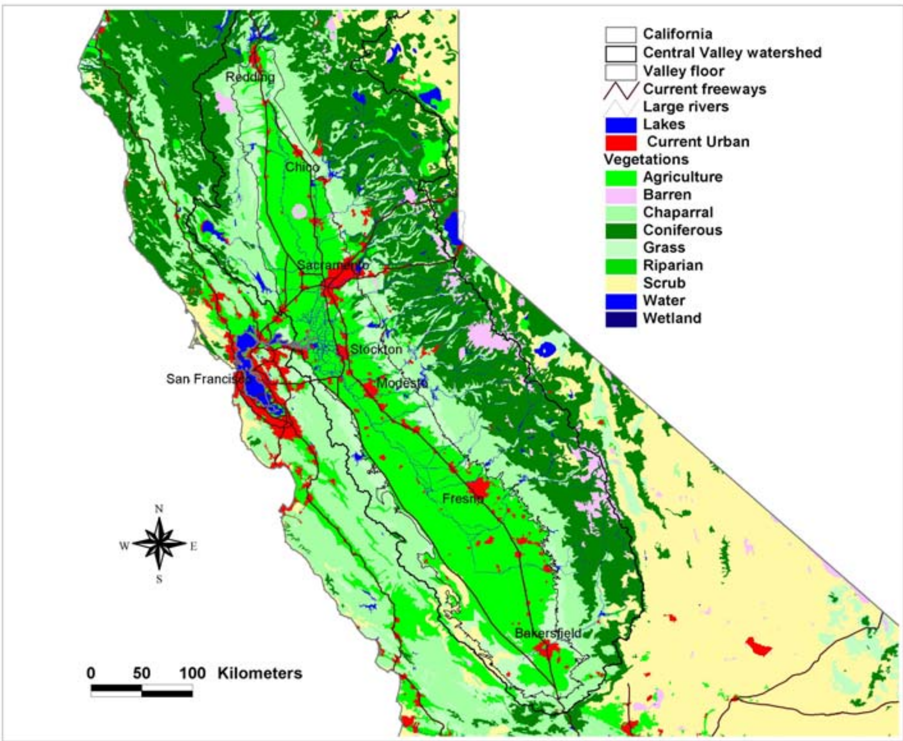
Physical Background

Physical geography helps determine human settlement patterns, so it is worth mentioning before discussing urban development. The major natural vegetation of California's Central Valley was California prairie occupying the valley floor (Map 1). Marsh grasses were distributed in the bottom of the valley floor, which was flooded annually. Forests of deciduous broadleaves grew beside rivers and streams or in bottom lands. Oak woodland and chaparral were distributed on the foothills surrounding the valley floor. Coniferous forest covered mountains east and north of the Central Valley. The precipitation in the Central Valley basin is higher in the north and mountains, low in the south and valley floor. The northern mountains can have 60-90 inches (1524-2286 mm) of annual precipitation, while the southern valley floor has only 5 inches (127 mm). Two large rivers, Sacramento from the north, San Joaquin from the south, converge in a delta, and discharge water to the Pacific Ocean through San Francisco Bay. The Mediterranean climate in the Central Valley area determined that agriculture must rely heavily on irrigation. Water always critically affects human activity.

The Central Valley's landscape has changed continuously in the past 150 years. Indians lived a life of hunting and gathering before Europeans arrived. Their staple food was acorns. Fish and game were also important food resources. Water played an important role in Indian village location (Hundley, 2001). For convenient fresh water access for preparing acorns and abundant fish and game, villages were located on the banks of rivers, streams and lakes. Indian population density was low for thousands of years before the Spanish came. The Central Valley was virgin land before being turned into ranch lands. After a series of discovery, exploration, and founding, Spanish settlement of San Diego in 1769 started the era of missions and ranchos. Twenty one missions were established between 1796 and 1823 along the coast of California from San Diego to the Bay Area (Bean and Rawls, 1988). The colonial Spanish and Mexican settlements concentrated in coastal California (Lantis, 1989, p2), while several ranchos were established in the Central Valley by 1846. The crucial effect of the colonial period is that the missions set locations of many future urban developments, and the missions, pueblos, and presidios are embryos for future cities.

Since California became a state in 1850, farming in California has experienced three economic successions with overlaps (Lantis, 1989, p5). Pastoral sheep and cattle dominated between 1850 and 1880, which is the continuation of the ranchos. Dry grain farming dominated from the 1870s until 1900, and irrigation agriculture finally took over in the 1900s. The vineyards and orchards were among the first irrigated acreages developed in California before 1930. The Central Valley Project increased irrigated acreages in the Central Valley dramatically in the 1940s and 1950s. The expansion of irrigated farming set the base to form central places serving agri-businesses.

The Central Valley's natural vegetation was first converted into ranch land. Ranch land was replaced by dry grain farming. And later, irrigated farming replaced dry grain farming and dominated the Central Valley's landscape. After 1945, urban expansion started another round of landscape replacement, and new shopping malls and residential communities started to replace the irrigated farmland in the urban fringe. The land use conversion from agriculture to urban is irreversible. This makes the last round of landscape replacement different from the previous ones. And urban expansion is a concern of various interest groups.



Map 1. Vegetation in the Central Valley Area

Physical background affects urban growth in several ways. For example, the flood bypass located west of Sacramento blocked the cities' westward expansion, and interstate highways 80 and 5 created bridgehead effects. Two cities, Woodland and Davis, grew beyond the bridge in the west. People normally like to live in a flat area. More than 15% slope can be sorted as too steep for housing. Another physical factor is local topography. The ridge growth around the Bay can be explained as people like bay views and try to locate homes above the smog line.

Evolution of Transportation Systems

The evolution of transportation systems affected the urban pattern early in the age of urbanization. Before the railroad, water routes for paddlewheel streamers dominated the inland transportation and trade in the Central Valley. The river ports like Sacramento, Stockton, and Marysville were important commercial towns in that period. Since construction of the first transcontinental railroad in 1869, rail transportation began to dominate land transportation, and towns and cities started to grow along railroad lines. A study by Marr (1967) shows that wheat and other irrigated crops depended on the railroad. And thus the railroad established the framework for most of the minor cities through the expansion of irrigated agriculture.

The current city distribution patterns in the Central Valley were formed in the railroad period. However, physical background plays a crucial role in urban settlement patterns in the Central Valley. The formation of river ports is determined by the river flow and river bed condition. The Chain of alluvial fans along the foothills of the Sierra Nevada Mountains have high quality soil and convenient water supply, and so they are the first locations selected by settlers for ranching, dry cropping, and irrigated agriculture. The railroad line went through these early settlements to maximize profit. Thus, economic patterns are eventually based partially on earlier physical settings. If economic activity did not obey such physical settings, it wastes economic resources. Interstate 5 in the southern Central Valley area has only recently generated chain urban growth, since its construction decades ago. A major cause is that the poor soil and water quality in the south west portion of the valley floor does not support massive agricultural activity as in the south east portion.

The evolution of rail transportation also affected the urban settlement patterns. The building of electric intra-urban railway lines facilitated the growth of metropolitan areas, and created high density communities. The nation's first cable car was introduced at San Francisco in 1873. The intra-urban electric railways reached their height of importance between the 1890s and the beginning of the automobile age in 1919 (Bean and Rawls, p196). Even now, BART continues to be important for Bay Area transportation, light rail again runs in Sacramento's streets, and Amtrak carries a small portion of interurban traffic in California. The Amtrak line stretches through the Central Valley from Bakersfield to Redding, and has two connection linkages to the Bay Area.

Two major events led to urban sprawl in the USA in past decades: mass production of housing and interstate highway construction. In 1946, the Levitt Company acquired 4,000 acres of potato field 25 mile east of Manhattan on Long Island, New York and began to build Levittown (Gans, 1982). It is the starting point of American mass production of housing in the suburbs and decades of explosive suburban expansion. The Interstate Highway System is another key factor for America's post World War II urban expansion. Advocated by President Eisenhower, the Federal Aid Highway Act of 1956 was signed and the interstate highways began to spread cross the America landscape. The interstate highway system in the USA was basically finished by 1983.

Urban Growth and Farmland Protection

Since World War II, urban growth is a universal phenomenon across the United States. It stirs nationwide concern by different interest groups. On the one side, developers and planners are trying to produce enough communities to satisfy the ever-growing demand for housing and to improve traffic conditions in large cities and fast growing regions. On the other side, the farmland protectionists and environmentalists are engaging in preserving farmland, open space and the natural environment in the urban fringe.

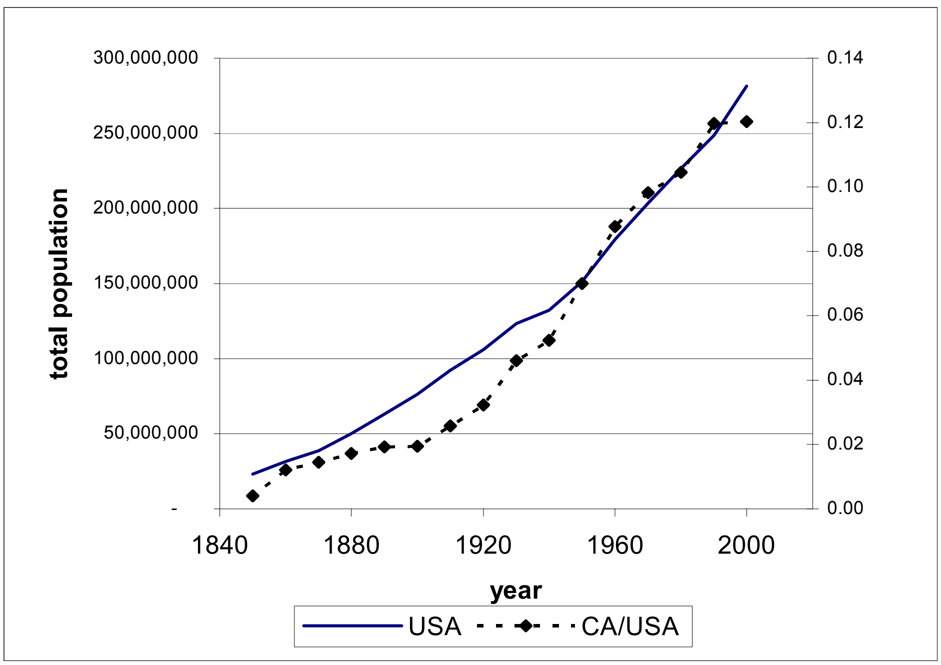


Figure 1. California's Population Growth vs. USA's

Farmland protection conflicts with America's worldwide reputation for its abundant land resources. The general consensus has been that there is little or no evidence to suggest that farmland conversion will significantly undermine food security or damage the economy, and that the strongest argument for preventing conversion is an aesthetic one (Kuminoff, et al, 2001). However, California belongs to America's Sunbelt (Sawers, 1984), and the mild weather attracted migration from the other states in past decades. California's coastal area encountered pressure both from manufacturing activity caused by the growth of military industries and export oriented high-tech industry and from population increase caused by internal and international immigration. Census data show that California's population growth is faster than the USA's, and California's urbanization rate is higher than the USA's (Figure 1). On the one hand, the urban sprawl creates low-density urbanized areas and the low density urban communities' transportation mostly relies on automobiles.

To study the pressure of population growth on land and water resources, we need to know: where was the urban growth in the Central Valley in past decades? What are the patterns and speed of land use change? Why did urban areas grow with that pattern? What is the economic reason and explanation? What will be the future growth patterns and speed? What shall we do to make things better?

By taking the Central Valley area in California as a case study, this study tries to find the motive for urban growth in past decades. The purpose of the study is to predict the future urban growth trends and patterns through studying the behavior of urban growth and to generalize some recommendations for efficient use of Central Valley's land and water resources.

CHAPTER 2

THEORIES AND CURRENT RESEARCH FINDINGS

Theories explaining urban growth can be categorized into five groups. 1). Location theory, transportation evolution and time-space conversion explained by external factors supporting urban growth. 2). Rank-size rule and central place theory explaining the rank-size pattern and spatial distribution of central places. 3). Von Thunen's theory, Alonso's household general equilibrium theory, and concentric zone models explaining urban expansion as a rational economic behavior of entrepreneurs and householders. 4). Growth pole theory, economic base theory and Lowry model analysis of internal factors pushing urban expansion. 5). Amenity factor and urban planning schemes illustrating the human factors affecting urban growth.

Location Theory, Transportation Evolution, Time-space Conversion

The industrial sector is often the base sector for growth of urbanized areas. Weber's theory of the location of industries (Weber, 1909) is the basic theory to explain urban growth. Weber stated that industrial location is influenced by seven location factors: raw materials, power, market, labor, political influences, industrial inertia and transportation. Central Valley's agriculture is dominated by fruits and vegetables. They are either perishable or weight loss, and thus the food processing industry is raw material oriented. The shape of the Central Valley and the distribution of irrigated land determined the urban patterns in the Central Valley area. The valley floor is a band stretching south-north in the center of California, which determines the basic linear pattern of urbanized areas in the Central Valley. The chain of cities is located on the east side of the valley floor, and stretches from Redding in the north to Bakersfield in the south. Hierarchical patterns need to be formed on an open plain background. This is not obvious in Central Valley area. The cluster pattern is the intermediate form of linear and hierarchical patterns. The valley floor is wider at Sacramento area and south of Fresno, the urbanized areas have cluster patterns in these two sections. West of Sacramento, there is an urbanized area cluster formed by Davis, Woodland, Dixon and Winters. South of Fresno, a cluster is formed by Visalia, Porterville, Tulare, Hanford and several other smaller urbanized areas.

High technology industry is labor oriented, and it will be the major urban growth pushing factor in the future. Los Angles, San Francisco, San Jose will continues their population growth. Their future spillover effects on Central Valley urban growth will substantial, for there is little land available to accommodate more urban population in these crowded areas, and the Central Valley is close to them with huge potential to accommodate spillover urban growth. Sacramento is surrounded by flat open space, is close to San Francisco Bay Area, and has an international airport. The location and situation is suitable for high technology, and thus it is expected to experience rapid urban expansion in the following decades. University of California will open a new campus at Merced in 2005. It is an incentive for high technology development in south Central Valley. Fresno's high technology industry is expected to grow in the future, and urban expansion as well.

The traditional way of studying urban growth focuses on transportation explanations, which reflects the effects of time-space conversion (Janelle, 1968). Adams (1970) studied the historical transportation factors shaping the urban built-up area. He classified the urban structural evolution into four stages: 1. Walking –horse car era, before 1870. The industrial revolution started in 1760s. In the first century of the industrial revolution, even with train systems well developed for inter city transportation, urban transportation was still dominated by walking or powered by animal in the 1870s. Since technology and material was not well developed, the community's population density at that time was not high. 2. Electric trolley era, 1870 to 1920. Cable cars were first introduced in San Francisco in 1873. The electric trolley system along with the skyscraper technology creates very high density urban centers, and the trolley line suburbs also formed a high density neighborhood by current standard. 3. Recreational automobile era, 1920 to1960. Federal Aid Road Act was passed in 1916. The federal highway system spread across American in the following three decades. Starting in the 1920s, the private automobile moved people to low-density suburbs, followed by shopping centers.. After WW II, massive shifts from transit to automobile commuting began. Buses overtake street cars in 1950s. And in the mean time, both rail transit and bus service was taken over by automobiles. 4. Freeway era, 1960 to present. It is the extension of the recreational automobile era. More people own cars and people are moving farther from downtown areas. Population density drops substantially. With each transportation innovation in the 20th century, urban areas sprawled further from the original core and the corresponding population density dropped.

Hartshorn (1992) further developed a detailed five-stage model of land use change in the freeway era after World War II: 1. Bedroom community, 1950s. Residential areas mushroomed in the suburb following Levittown style. 2. Independence, 1960s. Industrial and office parks moved to suburb, and regional shopping centers followed. 3. Catalytic growth, 1970s. Commercial and industrial land use developed in the suburb by following three styles: linear, cluster and large-scale center. 4. High rise in the new suburb, 1980s. High rises were developed in the suburb and suburban CBDs were formed. 5. Suburban town center, 1990s. Suburban downtown evolves to mature. This model explains the suburbanization process of large cities of 2 million and more population. Sacramento's total population is between 1 million and 2 million. Bedroom communities are popular in the urban fringe. Several communities started gaining independence and a few of them started catalytic growth.

The New Urbanism seeks to reconnect transportation with land use and in particular to establish transit-oriented development (Newman and Kenworthy, 1996). Encouraging high population density by developing light rail and subway systems is their main goal for future urban growth. Their idea of compact urban growth is welcomed by both developers and farmland protectionists.

Rank-size Rule and Central Place Theory

Zipf's law (Zipf, 1949) is commonly called the rank-size rule. It states a rank-size relationship for a region's urban system. According to the rank-size rule, the size of a given city can be predicted by its population rank among all cities in the area studied and the size of the largest city. The size of the nth largest city is one-nth of the largest city. It is a simple rule and has little theoretical importance, but the time series evolution of Zipf's law can be used to analyses the growth trends of cities with different sizes. Berry (1961) concluded that as countries become politically, economically, and socially more complex, they tend to develop normal (straight-line in log scale) rank-size distribution. According to Census data, the American cities (represented by urbanized areas) with size between 500, 000 and 2,000,000 have encountered tremendous growth in the past decades. Sacramento and Fresno belong to this category, and were expected to lead regional growth in the future.

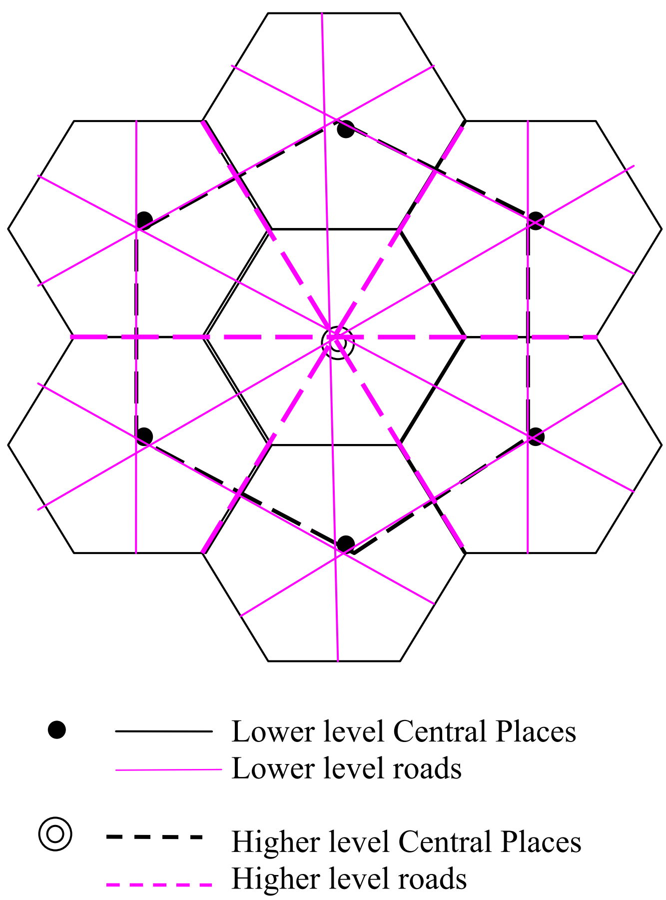


Figure 2. A K=3 Central Place Hierarchy by Market Principle

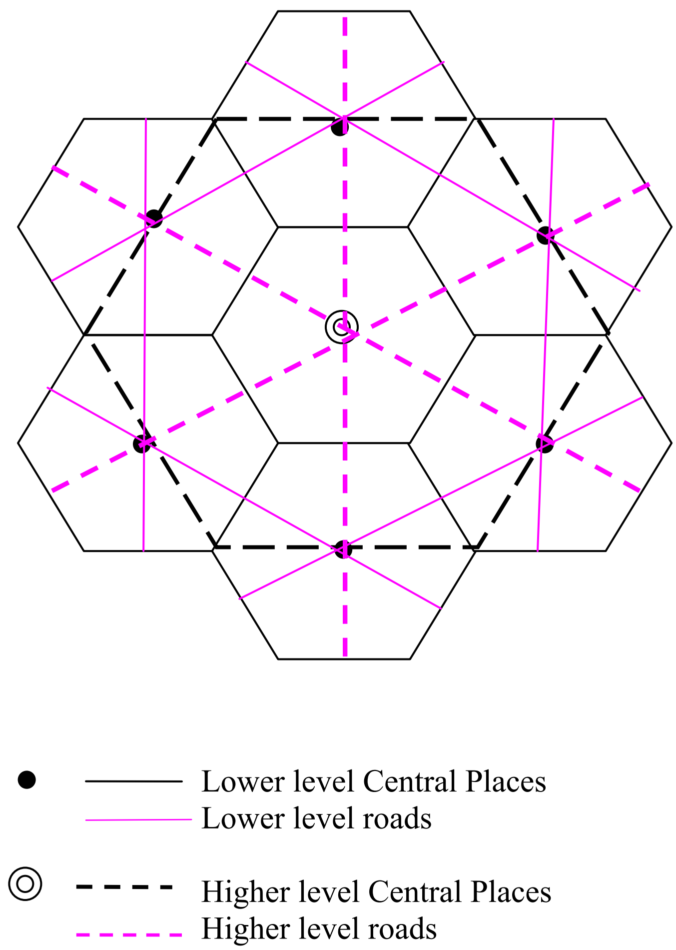


Figure 3. A K=4 Central Place Hierarchy by Transportation Principle

Central place theory provides an account of the size and distribution of settlement within an urban system (Christaller, 1933). In the market principle model (k=3, Figure 2) of organizing hierarchical spatial structure, central place theory assumes a dispersed rural farm population regularly spaced over a homogeneous plain, the consumer will always purchase from closest central place. And the seller will offer the good in the central places, whenever threshold purchasing power for a good is obtained at a central place. Christaller suggested that hierarchical structure of the central places will minimize the number of settlements serving an area if each settlement locates at the meeting point of three adjacent hexagons. In the transportation principle model (k=4, Figure 3), the criterion turns to minimize the lengths of roads to join adjacent pairs of central places.

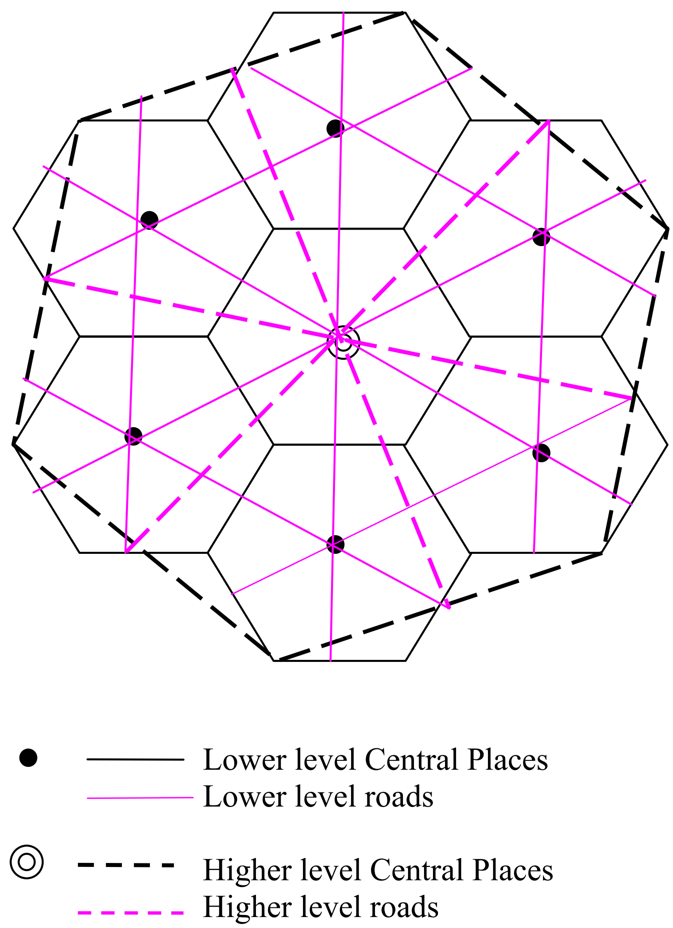


Figure 4. A K=7 Central Place Hierarchy by Administration Principle

The structure ends up with each settlement being placed on each side of a hexagon, and each is on the boundary of two rather than three hinterlands. In the administrative principle model (k=7, Figure 4), each lower order hinter land nested exclusively within the hinterland of the one higher order central place only. Losch extended Christaller's model to k=9, 12, 13, 16, 19, 21, and overlapped different models to find city rich and city poor sectors by rotation (Losch, 1940). Whereas Christaller's theory predicted a stepped hierarchical form to the city size distribution by assuming all places in an order had the same population, Losch's was consistent with a continuous distribution of population sizes, which is more realistic. Sacramento is the administrative center of California. It is also the major commercial center of the Central Valley region. Fresno is the second largest city in Central Valley area after Sacramento. It serves as the wholesale center for southern Central Valley area. For the basic assumption is not satisfied in the Central Valley area, it is hard to find an ideal hexagon pattern hinter land.

Von Thunen's Theory, Alonso's Theory and Concentric Zone Models

Von Thunen's Isolated State theory explained the concentric allocation of agricultural activities around an urban center (Von Thunen, 1826). It is the forerunner of the concentric urban model. The basic assumptions of Thunen's model are: 1. a city locates on the center of a homogenous plain suitable for agricultural activities, which forms an isolated state. 2. Horse drawn wagons are the only transportation method available for rural-urban trade. 3. the city is the only trade partner for the farmers. 4. farmers try to maximize their rent by selecting the proper agricultural products. 5. The transportation cost is in direct proportion to the weight of the agricultural product and distance to the market. The location rent for different crops are linear and decline in all directions with different slopes and intercepts. For a location with a given distance to the city, the crop with the highest location rent (bid rent curve) will be the best choice for the farmer at that location, resulting in the agricultural activities occurring in rings surrounding the central city. The most expensive agricultural products and the products with high transportation cost will be closer to the city, whereas the low value products and products with low transportation cost will be located farther from the city (Figure 5). Von Thunen's rings can be modified by cheap transportation route like river to form an oval pattern, and be further modified by several competing centers and arterial roads to form nested star-shaped rings.

Inspired by Von Thunen's model, Alonso-Beckmann's household general equilibrium theory represents the neoclassic economic approach for explaining urban growth (Figure 6). It is theoretically based on the concentric zone model. Harris and Ullman (1959) proposed three models of the internal patterns of North American Cities, the concentric zone model, the sector model, and the multi-nuclei model. Harris suggests a fourth model for American, the peripheral model (Bergman, 2003). If we relax the definition of CBD according to the transportation revolution, it may be linear (along the interstate highway), multi-centered (edge cities), or the combination of these two shapes. Through this way, the concentric zone model can be modified by major transportation lines and large edge cities, and thus can explain all the four models.

By taking space as a variable in utility function, and accounting rent and commuting cost in the budget constraint, the household general equilibrium model derives results that match real cities (Alonso, 1964, Beckmann, 1987, Yang, 1997). Even though this model has encountered some criticism, it was commonly applied in empirical studies with various modifications.

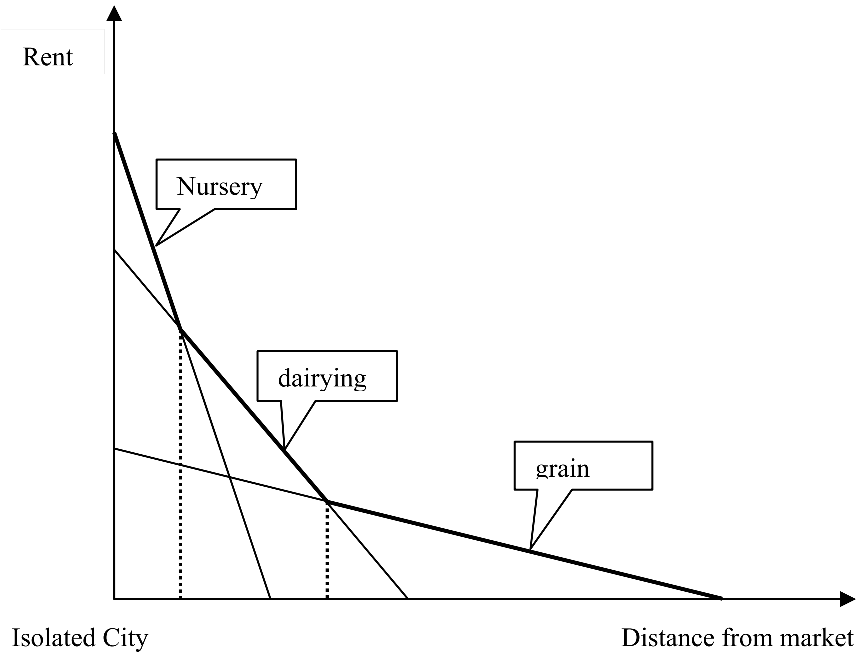


Figure 5. Von Thunen's Isolated City (Source: Cadwallader, 1996, P46)

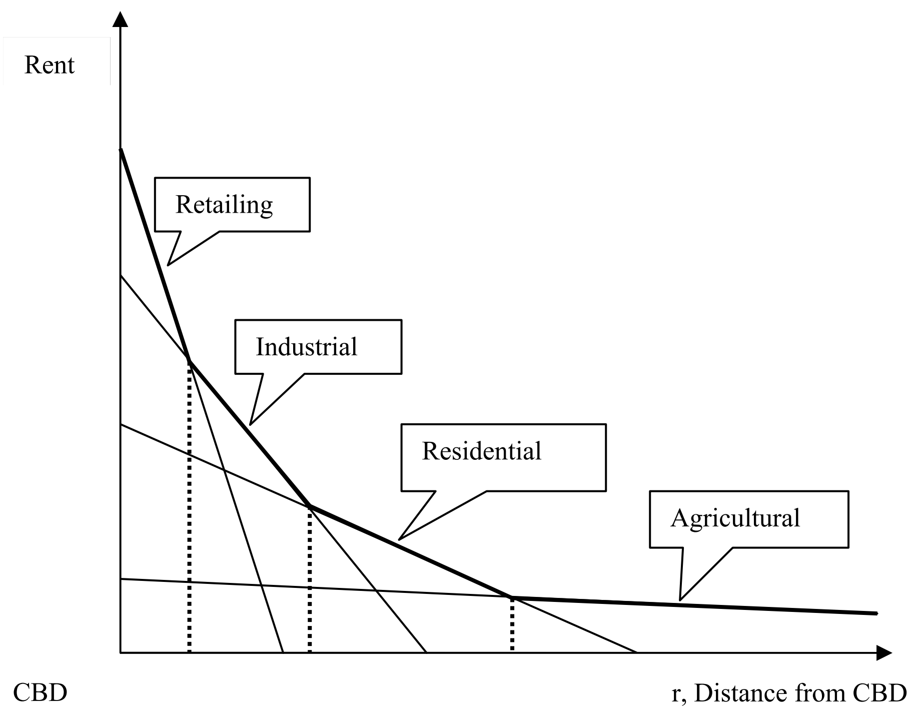


Figure 6. Relationship between Land Use and Distance from the City Center (modified from Cadwallader, 1996)

The related variables are determined by the core theory employed. I will introduce the Alonso-Beckmann's Household General Equilibrium Theory before examining which variables are needed in my research.

To model urban population density, major neoclassic economic assumptions will be employed. 1. The city has one center, the central business district (CBD). All employment opportunities are located within the CBD. 2. The city is located on a flat and featureless plain. 3. The transportation cost is linearly related to distance. 4. The land market is perfect competition without monopoly and government intervention. Each plot of land is sold to the highest bidder.

The theoretical model is that the households solve the utility maximizing problem:

$$Max\ u(q,r) = U\ (z(r),\ q) \qquad \text{---} \ 2.1$$

$$s.t.\ \ y = z + P(r) \bullet q + k(r) \qquad \text{---} \ 2.2$$

U (z, q): utility function; z: money;

q: space; y: income;

P(r): rent; k(r): commuting cost;

r: distance to CBD

Budget Constraint (BC) and First Order Condition (FOC):

$$\partial U/\partial z = \ \partial U/\partial q \ / \ P(r) \qquad \text{---} \ 2.3$$

Meaning: marginal utility of z divided by price of z (normalized as 1) equals marginal utility of q divided by price of q.

$$-\ (\partial P(r)/\partial r) \bullet\ q = \partial k(r)/\partial r \qquad \text{---} \ 2.4$$

Meaning: the decreasing rate of rent at r equals the increasing rate of commuting cost at r.

2.4 derives the slope of rent-biding curve

$\partial P(r)/\partial r = - \partial k(r)/\partial r / q$ -- 2.5

Budget constraint and 2.3 derive:

$q = (y - z - k(r)) \bullet \partial U/\partial z / \partial U/\partial q$ ------------------------------------- 2.6

Assume the commuting cost rate, ∂ k(r)/∂ r, is the same for rich and poor, According to 2.5 and 2.6 we conclude the following.

The increase of y with respect to distance to CBD derives the increase of q, and thus the increase of ∂ P(r)/∂ r, i. e. the rich take more space, the rich have a flatter bid rent curve, and so the rich prefer to live in the suburb.

Assume Ψ(u, r) is the household's rent biding curve (the maximum rent can be paid, given u level). The equilibrium point satisfies:

$\partial P(r)/\partial r = - \partial \Psi(u, r)/\partial r$ -------------- ------------------------------- 2.7

Actually, the rent curve is formed by many equilibrium points for different households, which fits households with different income level and different utility preferences. Assuming two groups of people bid for residential location, one group is rich, another one is poor. The rich group has flatter bid rent curves, and the equilibrium points form a flatter rent curve only for rich people. The poor group has steeper bid rent curves, and the equilibrium points form a steeper rent curve only for poor people. The two rent curves crossing at a point, which is the boundary between rich and poor. For a round area inside the point, the rent curve for the poor is higher, and thus will be occupied by poor people, for the ring area beyond the point, the rent curve for rich is higher, and thus will occupied by rich people. The argument can be extended to the competition of commercial activity and residential activity for land by rent bidding. The commercial activities have the steepest individual rent bidding curves and thus form a steepest rent curve, and will occupy central business districts by competition.

Concerning the spatial arrangement of land use and land value with cities, Alonso's model generates two testable propositions. First, land values should decrease in a curvilinear function with increasing distance from the city center. Second, it argues that land use will be arranged in a series of concentric zones radiating from the city center (Cadwallader, 1996). These were found by Seyfried (1963) and Mills (1972). Coulson (1991) concluded that Alonso's hypotheses concerning the spatial arrangement of land use and land value within cities seem to enjoy substantial empirical support. Criticism of Alonso's model mainly comes from the attacking of the assumption of free market economy in housing (Evans, 1983) and weakness in political concerns (Scott, 1980).

Empirical studies on agricultural land value in the near suburb are another examination on Alonso's model. According to Alonso's model, residential land use should compete with agricultural land use at the urban fringe. Urban land value should have a positive relationship with the background agricultural land value. The higher the agricultural land value, the higher is urban residential land value, and thus the higher is the marginal urban population density.

However, the real situation is that the market price for agricultural land reflects not only the agricultural productivity of land, but also potential future uses, especially in areas suitable for future urban development. In a competitive market, the price of land will equal the discounted sum of expected net returns obtained by allocating land to its most profitable use (Capozza, 1989). If agricultural production is currently the most profitable use, but development for some other purpose is expected to yield greater net returns in the future, then the current land price should reflect both uses in a simple additive form: the sum of the discounted stream of near-term rents from agriculture plus the discounted stream of expected rents from development beginning at some time in the future. A theoretical model is as follows. In a competitive market, where risk-neutral landowners seek to maximize the economic returns to their land, the market price of an agricultural parcel at time t that will be developed at t^* will be equivalent to the present discounted value of the stream of expected net agricultural returns from time t to t^* (the agriculture component) plus the present discounted value of the stream of expected net returns from the developed parcel subsequent to time t* (the development component).

The share value of future development in land price can act as an index of local potential urban development. Economists have analyzed the structure of agricultural land prices in an effort to understand potential threats to agriculture posed by land development. In the last decade, there has been rapid growth in the number of private land trusts in the USA, many of which are devoted to preserving agricultural land through the purchase of development rights. The correct estimate of the components of farmland value is useful for agricultural land preservation by funding the purchase of farmland conservation easements.

Decomposing farmland prices into their additive components can be of considerable value to understanding potential development paths, because high current land prices may reflect profitable current use, potential for a more profitable use in the future, or some combination of both. A major obstacle to such price component identification has been the obvious unobservable of the date of future development. Complicating matters further is the likely presence of option values associated with the land development decision.

Plantinga conducted a national-scale study of the determinants of agricultural land values in 2002 (Plantinga, 2002). Their theoretical basis for the empirical analysis is a spatial city model with stochastic returns to future land development. From the theoretical model, they derive an expression for the current price of agricultural land in terms of annual returns to agricultural production, the price of recently developed land parcels, and expressions involving model parameters that are represented in the empirical model. They also estimate the model of agricultural land values with a cross-section of approximately three thousand counties in the contiguous U.S. For each county, the share of the current land value attributable to future development rents was estimated. The results give a clearer indication of the magnitude of land development pressures and yield insights into policies to preserve farmland and associated environmental benefits. The result shows the contribution of future development rents to the 1997 value of agricultural land is 8% in California, 1% in Iowa, and 9% nation wide. Maps at county level shows the share may be higher than 50% in a county which has been mostly urbanized, such as Sacramento. The share is 30%-50% for Placer county and less than 5% for average parcels in Yuba and Yolo county.

Potential urban development is stronger in California than in Iowa, especially in the urban fringe and the areas with high possibility of being developed in the future. The capitalized value of annual crop rents can only reflect the agricultural productivity of land, but not the value of future development. In the center of Iowa, the share of future development in land value is almost zero, and thus I would expect to observe the sale price of agricultural land to equal the capitalized value of annual crop rents. However, this relationship does not hold in the urban fringe of California, for the share of future development in land value is more than 50%. The land value is much higher than the capitalized value of annual crop rents. The capitalized value of annual crop rents just reflects the agricultural productivity of land, an insignificant partial of the total land value. The result should be that agricultural land value is much higher in the urban fringe of California than in rural Iowa, but the capitalized value of annual crop rent should be very close between these two states if the agricultural productivity is about the same.

Land value and rent data from the California chapter of American Society of Farm Managers and Rural Appraisers in 2002 also support the above arguments. Comparing the rangeland of Shasta County and Sacramento County, Shasta has land values of \$50-\$200/acre and annual rents of \$10-\$18/acre, while Sacramento has land values of \$300-\$1000/acre and annual rents of \$1.46-\$25/acre. The average annual rent is close, while Sacramento has much higher land value than Shasta, for the possibility for Shasta's range land to get developed into urbanized area is almost zero, but the possibility of entering the urban fringe of Sacramento in the future is much larger. Estimated by the average land values (\$125/acre for Shasta, \$650/acre for Sacramento), the contribution of future development rents in Sacramento's agricultural land price is about 80%.

Growth Pole Theory, Economic Base Theory and Lowry Model

Growth pole theory is conceptualized by French planner Francois Perroux. Perroux recognized that economic growth was not balanced but disproportionately concentrated at certain points, and these points have priorities for resource allocation (Hartshorn, 1992).

Myrdal interpreted the mechanism of growth pole effects at the scale of an individual firm (Myrdal, 1957). The propulsive industry generates growth from its own purchase and sales through a circular and cumulative process. The expansion of the propulsive industry creates a multiplier effect, for increased purchases of material and more employment opportunity create additional job as money flows through the economy. Hirschman introduced the concept of polarization (Hirschman, 1957). As growth accelerates in the urban area, the hinterland experiences a parallel decline, which was labeled by Myrdal as a backwash effect (Myrdal, 1957). As time passes, a trickling-down process or spread effect (by Myrdal) will counteract the initial depletion of human and financial resources in the rural hinterland. The trickling down effect will dominate regional growth especially in the developed regions, which are in the post-industrial era.

According to growth pole theory, the regional economy is led by growth poles, the large cities. The growth poles affect the rest of the region's economy through spillover activity. In addition to Sacramento in the Central Valley area, three large cities located in the coastal area leaded California's urban growth in the past decades, Los Angeles, San Francisco, and San Diego. The San Francisco and Bay Area's urban growth has imposed direct spread effect on the Central Valley Area. The further expansion of Los Angeles will generate pressure on the Central Valley's land and water resources. The increasing water shortage in San Diego has generated water disputes between San Diego and neighboring Imperial Valley (Hundley, 2001), and it will create new pressure on the water resources of the Central Valley.

The economic base theory is stated formally in 1938 and 1939 (Hoyt, 1938, Weimer and Hoyt, 1939). According to the economic base approach, the local economy is driven by the sale of goods or services outside the community, and the regional economy is driven by the basic economy through multiplier effect. The revenues from export push local expansion by providing money to support service activities. Goods or services for exporting are basic, while employment related to local community is labeled nonbasic.

The Central Valley has the major concentration of land and water resources for California's future urban growth. Urban expansion in the Central Valley will generate negative externalities for the agricultural sector. Some of the Central Valley's agricultural land will be converted into urban usage, and the traditional agricultural sector will be weakened by the urban encroachment. The shrinking of agriculture will undermine the food processing industry and the Central Valley's export of agricultural products and the related services. The whole regional economy will be affected through reverse multiplier effects. Although normally the urban expansion will actually benefit local economy, for the positive multiplier effects overweigh negative effects, the transformation from agriculture to urban and its related problems should be studied.

Newton's law of gravitation in physics was introduced to social science realm by Ernest Ravenstein (1885) to study the migration patterns. It is widely used in human geography to study the flow patterns of migration, telephone, traffic, passenger movements, commodity flow, and other human and economic activities. The gravity model is employed by the Lowry model and thus is popularly applied in urban planning.

In 1964, Lowry published an urban economic model (Lowry, 1964) that has been extensively imitated and extended. Lowry's model is based on economic base theory, where a certain amount of employment is exporting or basic, and this exporting activity drives the economy. Employees in the basic industries demand housing and other services, and other (non-basic) employees are necessary to fill these demands. These other employees also have needs, of course, and so an infinite but converging chain of demands is created from the basic industry. Lowry's contribution was to extend economic base theory to a spatial system divided into zones. This is done by using gravity model type formulations to allocate the secondary employment to zones based on the distance to other zones and the population in the other zones, and to allocate the population to zones based on the distance to other zones and the employment in the other zones.

Lowry type models are commonly used in urban planning, through different modifications. MEPLAN is a model of land use and transport interaction (ME&P, 1989). MEPLAN is derived from the Lowry model, but it considers more comprehensively the housing market and its influence on population location. It includes the neo-classic bid-rent theory where individuals select residential locations as a tradeoff between their willingness to pay for residence at a location and related transportation costs. MEPLAN uses places of basic employment to calculate household locations, and then calculates the service employment needed to serve these households. What differentiates this model from other Lowry derivatives is the way the economic module operates. The economic module incorporates three economic concepts: input-output model (Leontieff 1951), price function and random utility. The solution mechanisms for the model are based on market mechanisms. Supply and demand of land in this model are linked by land price. Supply and demand of transport are linked by time and congestion.

In Alonso's model, the utility functions of households are normally taken to be identical, and the willingness to pay for land at different distances is related only to different budget constraints due to different incomes. This leads to a spatial arrangement of households according to income. Wealthier households are able to purchase more land at greater distances for they have the money available to pay for larger commutes, while poorer households have little choice but to compete for small amounts of space near to their work places. MEPLAN adopts many of the fundamental concepts of Alonso's model and monocentric theory. Most importantly, MEPLAN includes travel time and cost, land costs and elasticity of demand for land, and income as fundamental variables, and thus it can recreate the scenarios investigated in the monocentric theory. The most important difference between MEPLAN and the monocentric literature is that MEPLAN is not monocentric. Economic activities are allowed to occur in all zones, and each zone is treated as a mono-center.

In MEPLAN, households are typically divided into categories according to income, and thus spatial segregation by income can be modeled in a discrete way. In MEPLAN, various actors compete within different household categories for space, but the different budgets and average utility functions control which activity is more likely to outbid for space, and so the arrangement of activities and the market rent for land is still determined by a process similar to a bidding process in monocentric theory. The main difference is that MEPLAN uses random utility theory by assuming that the aggregate activity consists of a large number of individual actors each with an individual utility function. The wide range of utility functions is expressed by a random variable, and the mean of the random variable is assigned to a function. Thus although each actor in MEPLAN is given a single utility function, the MEPLAN utility function is actually the mean of a very large number of utility functions. This means that at any one location type there will be certain portions of different activities that are the highest bidders, and thus MEPLAN can simulate the randomness that occurs in real cities. Wilson's statistical gravity model and Random Utility Theory (Wilson 1967) provided a statistical interpretation of the gravity model, showing that the logit form of trip distribution corresponded to the most likely statistical arrangement of trips given constraints on the total amount of travel. Further development (McFadden 1973) used multinomial logit, nested logit, and the formulations of choice for discrete choice modeling. They provided both a statistical and economic theory for understanding and interpreting the properties and results of models. MEPLAN uses multinomial logit and nested logit models extensively, making it consistent with the theories as developed by Wilson and McFadden.

MEPLAN's constraints on land and the elasticity of land consumption give a market clearing price for land. An input-output model is applied to represent flows between activities in the form of demand for space. The coefficients of the input-output model are used to calculate prices in an elastic form to represent land allocation within zones. These prices are combined with the input-output relationships to give a price for every other factor, and all these prices are used together with the travel impeders in the allocation models. The prices can also be used to adjust the consumption and production functions that are implied in the coefficients of the input-output model. MEPLAN can include the incremental model for adjusting the constraints on space and the arrangement of basic activity, and then uses travel impeders from a previous time period, making it quasi-dynamic.

MEPLAN has many similarities to Lowry's model. Both are based on economic base theory, although the input-output model in MEPLAN is a more comprehensive extension of the theory. Both use gravity type models to allocate secondary employment based on travel difficulty to households, and to allocate households based on travel difficulty to employment locations. The spatial allocation models in MEPLAN are based on logit random utility models, which make them more behavioral and easier to interpret than strict gravity models, and also allow the inclusion of price information. Lowry's model does not include a direct preference for greater land consumption, instead using an upper bound constraint on density. The other major differences between MEPLAN and a Lowry model appear to be: MEPLAN is more comprehensive, with multiple types of land, floor space, industry, employment and households, and with a choice of functions for most of the relationships. Inter-industry and inter-household dependencies are also represented. And thus, MEPLAN is more suitable for detail urban planning than the simple Lowry model.

MEPLAN is based on several well established economic theories (Abraham, 1998). Its use of behavioral logit models is theoretically and practically appealing, making interpretation of results and selection of parameters easier. The use of utility maximizing formulations of household consumption make it consistent with monocentric theory, while the use of input-output modeling makes it easy to apply to regional problems. The inclusion of many different industrial factors allows a more comprehensive model of the economy than models that only emphasize the housing industry. The incremental model in MEPLAN allows for a wide variety of formulations describing how development and redevelopment occur through time, which seems to be a central component of many urban economic models. MEPLAN contains a sophisticated transport model, allowing it to examine detailed transportation infrastructure plans and to produce results describing the conditions of transportation networks.

Amenity Factor, Urban Planning and Environmental Protection

The emergence of an amenity factor to urban growth can be traced back to sunbelt urban booming in the 1970s. The attractive environment and balmy weather in the sunbelt states is a major factor fostering the sunbelt growth. At the local level, physical geographic factors can significantly influence urban growth patterns away from what economic factors might produce. The case study of New England cities shows that a strong positive relationship between altitude and income appears to be a persistent pattern of modern American cities (Meyer, 1994). A case study of Sydney, Australia also shows that the combinations of housing cost and environmental amenities influence the characteristics of people who choose to locate in suburban settings (Burnley and Murphy, 1995). Mueller-Wille (1990) analyzed 1970 and 1980 data on the distribution of population in the Chicago suburban area. Through statistical study of the population density data and qualitative study of the population density change, he finds that the physical geographic landscape elements have a statistically measurable influence on the spatial variation of population density. I (Liang, 2000) also find that with the traditional economic factors and zoning regulations still exerting strong impact on urban growth, other factors like amenity and environmental protection started to shape urban growth in Chicago area.

People want not only a larger space to live in, but also a large space near an amenity location close to the natural environment. Rivers, lakes, wetlands, flat topography or slopes on the urban fringe may be strong factors that entice people currently living in the core area. And thus amenity factors also affect urban growth in the Central Valley area. The lakeshore community development in Lake Tahoe and Clear Lake has raised the land value significantly. The mountain orientation for the Sacramento urban growth may be explained as the people like the mountain view and hilly landscape, or fog free altitude. And the flourish of lake front community on Folsom Lake east of Sacramento is another indicator of the effect of amenity factors. The Mediterranean climate in the Central valley is famous for its dry summer; manmade pools and fountains are important items for real estate dealers to attract customers. Several key shaped manmade pools (water front subdivisions) can be found on the Landsat 7 image published recently; one of them is located in northwest Sacramento. Tree canopies and green grasses are critical for amenity in the dry summer, and thus urban landscaping consumes large amounts of water in the Central Valley. Water availability is also important for local urban growth.

Different organizations are concerned with Central Valley's urban growth from different perspectives. We can classify them into three categories: developers, conservationist, and neutral agents falling between these two.

On the human impact of urban growth, urban planning activity plays an important role. A series of pro-zoning movements between 1900 and 1916 led to Euclidean Zoning in 1926, such as the city beautiful movement, the garden City movement, public regulations, and the progressive movement. Different levels of zoning activities shaped the America's urban landscape dramatically in the following decades (Platt, 1996).

The Sacramento Area Council of Governments (SACOG) is an association of Sacramento Valley governments formed from the six regional counties - El Dorado, Placer, Sacramento, Sutter, Yolo and Yuba and the 22 member cities. Its primary function is to provide regional transportation planning and funding. SACOG prepares the region's long-range transportation plan, and it is undertaking a new program to link transportation and land development more closely.

SACOG's base case study is a projection of how the area would grow if current local trends continue. It projects where future growth will occur during the next 50 years. According to the study, the six county region will remain an attractive place to live and will grow dramatically. One of the most startling figures to arise from the study is that there will be an estimated 1.7 million more people in the Sacramento Region in 2050 than the 1.9 million in 2000. The base case future land use map shows that the urbanized areas in the six counties at 2050 will be approximately three times as large as current urban area. Even through the base case is just a model result, SACOG's aggressive planning may generate substantial consequences for the future urban growth in the Greater Sacramento Area.

Caltrans identifies its purpose as to promote California's economic vitality and enhancing its quality of life by providing for the mobility of people, goods, services and information (DOT, 2002). Caltrans is responsible for planning, designing, building, operating and maintaining California's state highway system, and over time, its role has evolved to include rail and mass transit. In the face of the state's burgeoning population, increased congestion and stubborn environmental pollution, Caltrans has moved to include new factors in its duties, such as, land use, environmental standards, and the formation of partnerships between private industry and local, State and Federal agencies.

The Light Rail associations like Light Rail Progress support development of the light rail system. Large American urban areas with rail transit systems serving major travel corridors have significantly lower rates of congestion growth than cities without rail transit. In these urban areas with rail, traffic congestion appears to be increasing, but at a rate 42% lower than in similar urban areas without rail, according to a study completed in October 2000 by Mobility Planning Associates of Austin, Texas (LRP, 2001). The study results clearly have implications for cities considering the installation of new light rail systems.

Both farmland protection and environmental protection activity are strong in the Central Valley. One active conservation organization is American Farmland Trust (AFT). It is a national, nonprofit organization working to stop the loss of productive farmland and to promote farming practices that lead to a healthy environment. Based on the correlation of large amounts of prime farmland with high rates of farmland conversion, AFT identified the twenty most threatened regions. Sacramento and San Joaquin Valleys of central California ranked the first among the twenty based on the market value of agricultural products, development pressure and land quality (AFT, 1997). AFT's computer simulation of alternatives for future urban growth in California's Central Valley shows that low-density urban sprawl will consume far more farmland than is necessary to house the anticipated population increase (AFT, 2002). AFT stated that the resulting waste of irreplaceable agricultural resources, not to mention billions of tax dollars, would be tragic. AFT encourages a more compact, efficient pattern of urban development that remains distinctly Californian in character. Approximately 83% of the US's agricultural land was devoted to agricultural production for domestic consumption, while 17% contributed to export and soil conservation or was uncultivated. But according to the farmland protectionists' estimation, the high rate of US population growth combined with continued conversion of agricultural land will eliminate the current 17% cushion by 2020 (Olson and Lyson, 1999). Gever (1986) predicts that the US will cease to be a net food exporter within the period 2007 to 2050.

Farmland Mapping and Monitoring Program (FMMP) is a program conducted by the Division of Land Resource Protection, California Department of Conservation to keep a consistent archive of information about California's changing land use. The FMMP is funded through the state's Soil Conservation Fund. This fund receives revenues from Williamson Act contract cancellation fees. The goal of FMMP is to provide consistent and impartial data to decision makers for use in assessing present status, reviewing trends, and planning for the future of California's agricultural land resources. FMMP produces important farmland maps, which are a hybrid of resource quality (soils) and land use information. Data are also released in statistical formats, principally through the biennial California Farmland Conversion Report.

Sacramento Valley Conservancy is another active conservative organization. The Conservancy was founded in 1990 on two basic principles - that open lands are necessary for quality of life and that we must care for the land today so future generations may enjoy its physical and spiritual benefits tomorrow. Its mission is to preserve the beauty, character and diversity of the Sacramento Valley landscape by working with citizens, property owners, developers, public agencies and other nonprofit organizations. It arranges for the preservation of lands for agricultural, natural resource protection, recreation, and wildlife habitat.

US Geological Survey documented the spatial data for the whole Central Valley area, which is critical to support the study of urban expansion process by different interest groups. In 1900 only small urban cores were established in San Francisco, Oakland, Sacramento, San Jose, Stockton, and Alameda. Substantial urban growth followed in the 20th century, especially after the Second World War. In 1996 a strong national economy contributed to increased urban growth and significant infill development. The growing prominence of the Highway 99 corridor becomes apparent. The Central Valley approached a linear city system anchored by Redding and Bakersfield at each end with numerous cities in-between. According to USGS's statistic data, 24% of the state's irrigated farmland is converted to urban uses between 1950 and 1994 (USGS, 2002).

US Census Bureau provides demographic data useful for monitoring the urban population growth. Detailed population growth patterns can be mapped by Census tract or other census units, which can show the suburbanization process and identify the hot growth spots.

University of California at Berkeley's Sacramento Program is conducted by its Institute of Urban and Regional Development. The Institute studies the processes of urban and regional growth and decline, and effects of governing policies on the patterns and processes of development (IURD, 2002). Currently their research focuses on urban growth subjects such as sustainable development and regulation of urban growth and land use, evolving patterns of suburbanization and central city reconstruction, transportation alternatives, including high-speed rail and transit-based land development.

Through manipulating the Census population data and GIS land use data, we will investigate the urban structure in the following chapters. Chapter 3 will document the data collection and data availability. Chapter 4 will study the rank-size distribution, and the central place structure and evolution. Chapter 5 will derive empirical functions by applying Alonso's theory, and test the model by real world data in the study area. Chapter 6 will use multivariable models to simulate the spatial patterns of population and housing cost density for Sacramento and Fresno. Chapter 7 will apply Lowry model at zip code scale for Sacramento and Fresno cases. Chapter 8 will study the urban expansion trends and find the relationship between the agricultural land value and the neighboring urban population density. Chapter 9 will forecast the urban expansion according to the population forecast by California Department of Finance. Chapter 10 will probe the way for efficient urban growth by applying the neoclassic economic principles on major urbanized areas in the Central Valley.

CHAPTER 3

DATA

Census and Land Use Data

To study the rank-size rule, two sets of data can be evaluated. They are population for MSA and population for urbanized area. Both of them can be downloaded from the American Factfinder in the Census Bureau's website (US Census Bureau, 2003). The 2000 Census have geographic coordinates by 1 millionth degree for each records represent the geographic location of the selected geographic unites, which can be used to calculate distances and gravity forces. The drawback is that the data set did not show the MSA and Urbanized Areas by state. The first step treatment of the data is to pull out California's MSA and Urbanized Area data from the nation wide data set. The Central Valley's data can be abstract from the California data set.

The Central Valley can be defined by the watershed for Sacramento River and San Joaquin River. For convenient population and land use data collection, the whole county will be taken if it partially belongs to the Central Valley watershed. The study area covers 30 of the 58 counties of California. The Central Valley area can be classified as three regions by different landforms, the valley floor, the foothill, and high mountains. The valley floor is mostly developed into farmland. The foothills surrounding the valley floor is mainly used for ranching. The high mountains area is mainly forested. Intensive current studies by FMMP (2003, Farmland Mapping and Monitoring Program, California Department of Conservation) and DWR (2003, California Department of Water resources) are concentrated on the valley floor. While more concern is located on the valley floor in my study, the foot hill and mountain area will also be studied for forecasting future urban growth and related water resources allocation.

The GIS data includes two major categories: 1. GIS data for population density and housing cost distribution, 2. GIS data for time series land use change. The population density and housing cost data (Census data) at Census Block Group (CBG) level are collected for major urbanized areas in the Central Valley, and the land use data for the whole region (30 counties) are collected by time intersections. The sampling strategy for Census data is to take typical cities in the Central Valley area. The top 15 largest cities are studied for their relative importance in leading the Central Valley's urban growth. 17 urbanized areas selected with their population in 2000 are shown in Table 1.

Table 1. The Sampled Cities and Their Population in 2000

Rank	UA name	Population	Rank	UA name	Population
1	Sacramento	1393498	10	Yuba City	97645
2	Fresno	554923	11	Vacaville	90264
3	Stockton	313392	12	Chico	89221
4	Modesto	310945	13	Lodi	83735
5	Bakersfield	268800	14	Hanford	69639
6	Antioch	139453	15	Turlock	69507
7	Visalia	120044	21	Woodland	49168
8	Merced	110483	23	Delano	39512
9	Redding	105267			

For the population density trend analysis, data at Census tract level is collected for the whole study area (30 counties). The boundary change between 1990 and 2000 at census block group level is too large to make meaningful comparisons. Therefore, for time series consumer behavior analysis, only the two largest cities, Sacramento and Fresno, will be studied at Census tract level in both 1990 and 2000.

The census data analysis unit will be based mainly on the census block group, for it is the most detailed level of census data available on the web for free, and it is detailed enough to do the GIS modeling for the study. Such as the city of Chico in northern part of the Central Valley, with a population close to 90,000, it has 82 census block groups. For the largest cities, Sacramento and Fresno, both census block group and census tract data are used in modeling their urban population density and housing cost patterns. Census tract data eliminate the differences between census block groups in the same tract. This normally can raise the R square in modeling.

The sample data Summary Tape File 3 (US Census Bureau, 2003) for Census 1990 contains sample data weighted to represent total population for 34 population items and 27 housing items and 100-percent counts and un-weighted sample counts for total persons and total housing units. The Sample Data Summary File 3(US Census Bureau, 2002) Census 2000 presents detailed population and housing data (such as place of birth, education, employment status, income, value of housing unit, year structure built) collected from a 1-in-6 sample and weighted to represent the total population. The data is available at web site http://factfinder.census.gov/servlet/BasicFactsServlet?_lang=en

Table 2. Variable comparison between 1990 and 2000 Census

1990 code	1990 meaning	2000 code	2000 meaning
P0010001	Persons: Total	P001001	Total population: Total
P080A001	Households: Median household income in 1989	P053001	Households: Median household income in 1999
not on list	calculate by H0080001 + H0080002	H007001	Occupied housing units: Total
H0080001	Occupied housing units: Owner occupied	H007002	Occupied housing units: Owner occupied
H0080002	Occupied housing units: Renter occupied	H007003	Occupied housing units: Renter occupied
H050A001	Specified renter-occupied housing units paying cash rent: Median gross rent as a percentage of household income in 1989	H070001	Specified renter-occupied housing units paying cash rent: Median gross rent as a percentage of household income in 1999
not on list	calculated by using H058A001 and H058A002, according to the statistical relationship between H095001 and H095002, H095003 in 2000	H095001	Specified owner-occupied housing units: Median selected monthly owner costs as a percentage of household income in 1999 ; Total
H058A001	Specified owner-occupied housing units: Median selected monthly owner costs as a percentage of household income in 1989; With a mortgage	H095002	Specified owner-occupied housing units: Median selected monthly owner costs as a percentage of household income in 1999 ; Housing units with a mortgage
H058A002	Specified owner-occupied housing units: Median selected monthly owner costs as a percentage of household income in 1989; Not mortgaged	H095003	Specified owner-occupied housing units: Median selected monthly owner costs as a percentage of household income in 1999 ; Housing units without a mortgage

One technological problem in census data collection is that the variable listing is different between 1990 and 2000 censuses. Some modification is needed for 1990 data to match with 2000's, such as no variable in 1990 matches H007001 and H095001 in 2000, but the variable can be calculated from related variables in 1990. The variable match between 1990 and 2000 is listed at Table 2.

The land use data collection depends on the data availability. The current available land use data on the web are: 1. LULC (land use land cover) data in 1975 and 1992 by USGS(2003). 2. Land use data in 1990 and 2000 by FMMP (Farmland Mapping and Monitoring Program, Department of Conservation). 3. Land Use Data in 1998 (1996-2000) by DWR (The California Department of Water Resources). 4. Multi-source Land Cover Data in 2002 by FRAP (2003, Fire and Resource Assessment Program, the California Department of Forestry and Fire Protection). The time intersections available are 1975, 1990, 1992, 1998, 2000, and 2002. LULC data by USGS in 1992 and land use data by FRAP in 2002 are based on satellite image. They are not compatible with other land use data by both resolution and accuracy, and thus they will just be used as reference data in my study.

Evaluating GIS Data

Three different sets of land use GIS data sources are employed to reflect the time series change of urban land use patterns. They are FMMP data for 1990 and 2000, DWR data for 1998, and USGS data for 1975. FMMP land use data is created by State of California, Department of Conservation, Division of Land Resource Protection, Farmland Mapping and Monitoring Program. The data is available biennially starting at 1984. The data set began to cover most Central Valley counties in 1990. The data set for 2002 is under construction, and thus the latest data available is 2000. USGS land use and land cover digital data for 1975 is digitized by U.S. Geological Survey in 1990 from 1:250,000 and 1:100,000 scale maps (USGS, 1990). Limitations of the USGS land use data for 1975 are each quadrangle of land use data has a different representative date. The date ranges from 1970s to early 1980s. The year 1975 is identified by taking the average date. DWR land use data for 1998 are created by California Department of Water Resources, through its Division of Planning and Local Assistance. The data was gathered by using aerial photography and extensive field visits. And it was done county by county. For each year the program only covers several counties, the most resent DWR data set covering the Central Valley are gathered by aerial photography taken from 1996 to 2000, and thus 1998 is taken as the reprehensive date for the data. Not only it is difficult to decide which year of data should be used, the data employed may have different projection and geo-referencing system, different category, different resolution, and different emphasis and purpose as well. Countermeasures are needed to unify the map projections, match the categories, group the data by similar resolution, and only analyze the data sources that are comparable.

To unify the map projection, the projection used by FMMP are selected as the final map projection, for FMMP have two data sets and its projection is been commonly used by other GIS data sources for California, such as USGS's transportation data. The parameters for this projection are as followed.

Projection: Albers Equal Area

Datum: NAD 27

Ellipsoid: Clarke 1866

Longitude of Origin: -120:00:00

Latitude of Origin: 0:00:00

Standard Parallel 1: 34:00:00

Standard Parallel 2: 40:30:00

False Easting: 0.00 meters

False Northing: -4,000,000.000 meters

Notice that the datum taken in this projection is NAD 27 (North American Datum 1927). Other GIS sources (Census Bureau) may use NAD 83, which has different ellipsoid and may have minor global error in the process of projection transformation. Metadata (DWR, 2001) shows that the map projection for DWR data is Transverse Mercator with 500,000 meters of False Easting. The map projection for USGS land use data is Albers Equal Area but with different parameters. These different map projections can be unified by projection transformation through Arc Info or higher version of Arc View, such as Arc View 3.2. When DWR and USGS GIS data are transformed into the united projection, the feature boundary match has as large as 40 meters error in some locations. The accuracy of total area for different categories by county may be more reliable than the boundary match, for total area for each land use category will not change severely in the map transformation as the position of their boundary lines.

USGS's LUDA 1975 land use category is a standard category, and covered all kinds of land use. Its urban subcategories include the classes like residential, commercial, and industrial, and can be used to test the concentric zone model. Range land and agricultural lands are two different categories, and cropland and orchards are separate in its agricultural lands category, which makes it possible to analyze the spatial relationship between urban growth and different farming activities. Water and wetland are two different categories, with detailed subcategories, which make it possible to analyze the relationship of settlement pattern and water bodies and flood zones. The forest land is divided into two subcategories, deciduous and evergreen, along with the tundra and ice, their zonal distribution illustrate the altitude of the mountain area. The vertical zones of the natural vegetation in the Central Valley area are irrigated agriculture in the valley floor, perennial grass and chaparral woodland ranching in the foothill, coniferous forest in the high mountain, and tundra and ice above the tree line on the top of high mountains.

FMMP land use categories (FMMP, 2001) concentrate on mapping prime farmland, and the definition for different kinds of farmland in terms of relative importance is very clear. Such as, Prime Farmland (P) is defined as irrigated land with the best combination of physical and chemical features able to sustain long term production of agricultural crops.

The irrigation status can also be identified through the farmland definition, but is not as accurate as the data by DWR. The urban category has no subcategory and thus can not be used to study urban structure.

DWR has a very detailed land use classification system. Listed below is just the highlight of its level one category by 1999 classification (DWR, 2001): 1. Agricultural Classes, 2. Semi-agricultural Class, 3. Urban Classes, 4. Native Classes, 5. Unclassified. In the Agricultural Classes, the subclass differentiates field and fruit crops according to their water consumption situation, and rice is a single sub-category for it is an extreme case in water consumption. Residential, Commercial, Industrial, and Urban Landscape are subcategories in the urban classes, which make it convenient to study urban land use patterns and internal structures. The urban landscape category shows the location of green belts in urbanized areas, which is useful for population density pattern studies and allocate amenity factors affecting the urban residential patterns. The major land use categories of DWR, USGS, and FMMP are listed in Appendix 2.

The differences between land uses categories make it difficult to study detailed urban land use. Urban land use has just one category- “D” (Urban and Built-Up Land) in FMMP data, because the data set concerns mainly farm land categories. The data set by DWR has several detailed subcategories for urban land uses: U – Urban (combined), UR – Residential, UC – Commercial, UI – Industrial, UL - Urban Landscape, and UV – Vacant. Urban land use is categorized in USGS data as Urban or built-up land with 7 detailed subcategories: Residential, Commercial and services, Industrial, Transportation communication and utilities, Industrial and commercial complexes, Mixed urban or built-up land, other urban or built-up land. The criteria for detailed urban categories differ between DWR and USGS, and thus spatial analysis on time series change can not conducted by detailed categories based on these two data sets. To solve this category match problem, and make the data comparable, the urban categories are unified to one category, urban land use. The detailed land use information is discarded unfortunately for time series comparison purpose, but they are still useful in urban spatial structure analysis for large urbanized areas.

Land use map resolution can be measured by the area of minimum polygon in the study area. The resolution for USGS data is 500 square meters, which is close to DWR data’s 0.1 acre (405 square meters). The resolution for FMMP data is 1 acre (4047 square meters). Obviously, USGS data can be compared with DWR data in terms of map resolution, while it is not suitable to compare with FMMP data. Urban land area should be underestimated by FMMP data for 2000 compared with the DWR data in 1998, for small urban polygons are eliminated by FMMP.

The incomparability between FMMP data and other data sets also comes from the different mapping purposes and emphases. FMMP concentrates on farm land mapping. Its urban category is highly simplified and the resolution is coarse. Transportation lines linking cities and towns are all categorized as rural. This is unrealistic, for interstate highways are wide and take large pieces of land. Both DWR and USGS data have transportation lines and categorized them as urban, this is other evidence of the greater compatibility of these two land use GIS data sets. The non-cropping rural land uses, including farmsteads, dairies, livestock feed lots, and poultry farms, are classified as “S”, Semi-agricultural and Incidental to Agriculture in DWR data, while they are roughly categorized as “Other agriculture” in USGS data. This difference did not affect the data analysis for urban land use, for both DWR and USGS treated them in the rural land use category, not urban.

According to the above arguments, USGS 1975 and DWR 1998 data were used for high level estimates and forecasts, while use FMMP 1990 and 2000 data were used for low level estimation and forecasts for urban land uses in the Central Valley area. The result of the urban land use data analysis confirmed this characteristic of the data. The urban land use area at county level is much larger by DWR data in 1998 than FMMP data in 2000, and the gap exists when the data are used separately to forecast urban land use in 2010, 2020 and 2050. It is meaningful to have two sets of estimation and forecast, one shows the aggressive estimation, and the other shows the conservative estimation. It is hard to judge which estimation is better, for FMMP has time series as an advantage, while USGS and DWR has higher spatial resolution.

Through the data evaluation on different data sets above, we can conclude that the resolutions of data sets need to be united for the land use GIS data. However, in some cases, even when the resolution is united, the difference of spatial data collect style may generate mismatches between spatial data. USGS 1992 and FRAP 2002 land use data are derived from satellite images and are in grid format. The computer based land use classification can not match with the accuracy of the land use classification by human interpretation and field check confirmation. They are not comparable with the other data sets, and thus can just be used as references.

Other Related Data

In addition to the land use and census data sets, some related data, such as physical background, transportation networks, are available on the CaSIL (2003, California Spatial Information Library) website sponsored by the California Mapping Coordinating Committee. Most updated Landsat 7 images also available on CaSIL for land use conversion analysis, and the image is projected by Albers Equal Area projection using the same coordinate system selected for my GIS data sets. DWR has a set of large scale aero-photo image data for recent years, and can be used as reference for detailed land use analysis.

The agricultural land value data are available on the annual publication “Trend in agricultural land and lease values” by American Society of Farm Managers and Rural

Appraisers (ASFMRA, 2003). ASFMRA divides California into seven regions for its rural land price survey. Among the seven regions, Region 1, Sacramento and

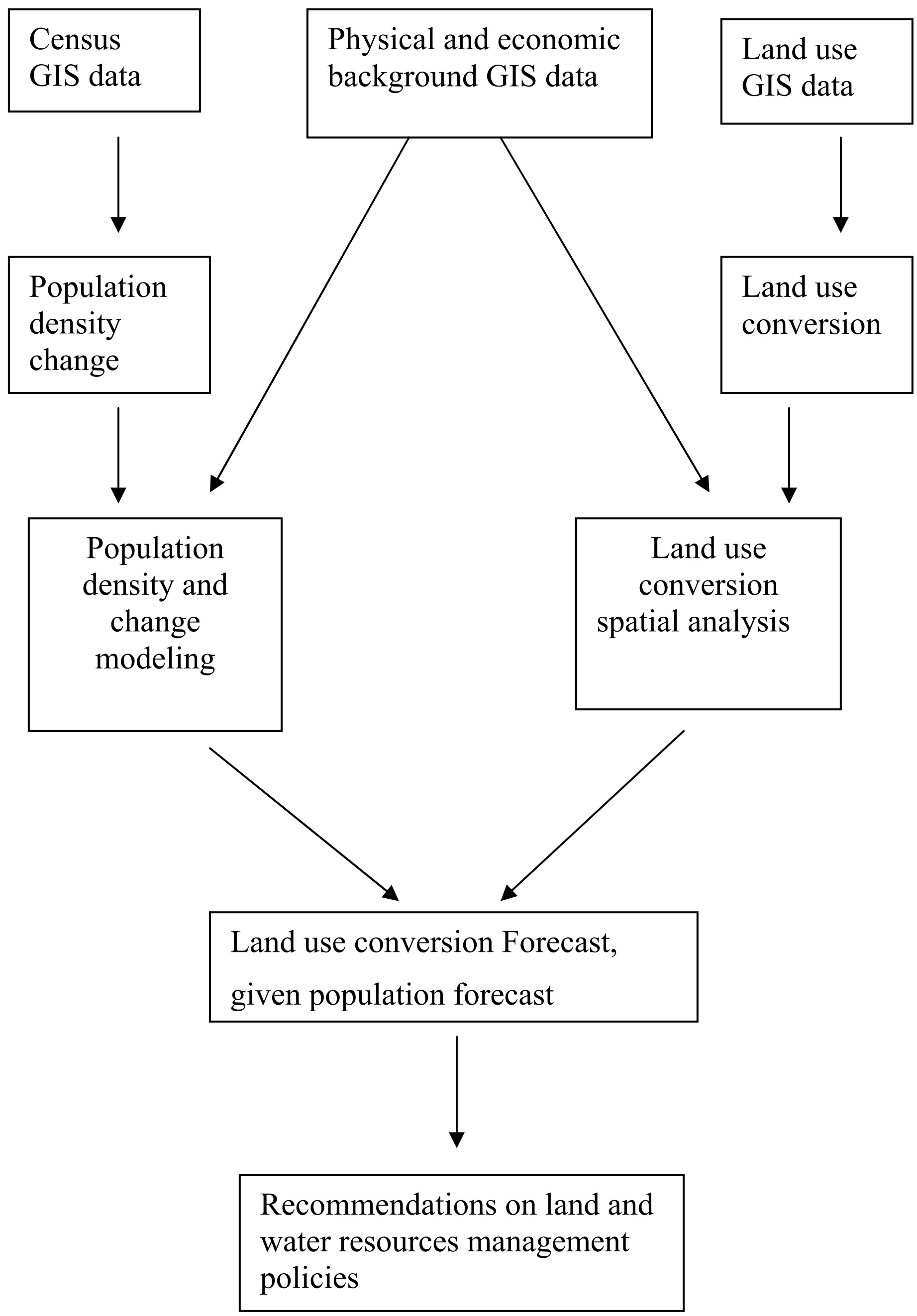


Figure 7. Flow Chart of GIS Processing on Land Use Conversion Spatial Analysis

intermountain valleys, Region 3, Northern San Joaquin Valley, Region 4, Central San Joaquin valley, and Region 5, Southern San Joaquin valley, cover the Central Valley area. In each region, several sub-regions are listed separately to show the land price and rent range for their major local cropping activities.

Field work is critical to examine the quality of the land use and census data. Photos taken in the field are helpful to visualize the data. I did some field trips to the urban fringe and downtown areas of Sacramento to investigate the urban land use patterns and land use changes.

The general procedure for land use conversion spatial analysis are on the one hand to do the spatial data analysis using GIS data, and also to model the population density and density change by manipulating census population data (Figure 7). GIS data describing the physical and economic background can be utilized as reference data in both of the spatial modeling and population density modeling. The combined result of these two models can be employed to forecast the land use conversion, while the current official population forecast is employed. The last stage of the study is to analyze the land and water resource conditions and the spatial match of the supply and demand of land and water resources. The measures and recommendations for efficient land and water resources usage can be concluded by applying the economic theories. The major difference between geographical analysis and pure economic analysis is that the spatial variables are incorporated into the geographical study, and physical factors can be taken into consideration through synthetical spatial analysis. The Lowry model requires data on both employment location and employee residency location. Mainly determined by the data availability of the employment location, Lowry model will take zip code as a study

Table 3. Employment Categories of Economic Census 1997 and Census 2000

1997 NAICS , by working place	US Census 2000 employment residential data categories
11 Agriculture, Forestry, Fishing, and Hunting 21 Mining 22 Utilities	P049030 Agriculture; forestry; fishing and hunting; and mining
23 Construction	P049033 Construction
31-33 Manufacturing	P049034 Manufacturing
42 Wholesale Trade	P049035 Wholesale trade
44-45 Retail Trade	P049036 Retail trade
48-49 Transportation and Warehousing	P049037 Transportation and warehousing; and utilities
51 Information	P049040 Information
52 Finance and Insurance 53 Real Estate and Rental and Leasing	P049041 Finance; insurance; real estate and rental and leasing
54 Professional, Scientific and Technical Services 55 Management of Companies and Enterprises 56 Administrative and Support and Waste Management and Remediation Services	P049044 Professional; scientific; management; administrative; and waste management services
61 Educational Services 62 Health Care and Social Assistance	P049048 Educational; health and social services
71 Arts, Entertainment and Recreation 72 Accommodation and Food Services	P049051 Arts; entertainment; recreation; accommodation and food services
92 Public Administration	P049055 Public administration

unit. US Economic Census at 1997 (US Census Bureau, 2003) shows the zip code as the most detailed employment data unit. The Census population data set in 2000 has zip code category to match with the Economic Census data (Table 3). Categories of Economic Census in 1997 are coded by the North American Industry Classification System (US Census Bureau, NAICS, 2003). NAICS was developed jointly by the U.S., Canada, and Mexico to provide new comparability in statistics about business activity across North America. US Census 2000 data for employee residence is available for 5 digit zip code areas. The employment data code start at P049001 and end at P049055. The data list male and female separately, and has 13 categories and 20 sub categories. The Census 2000 employment classification is easy to match with the Economic Census 1997 employment classification. The 2000 Census data also has data for employees' commuting time. The commuting time can be used to test the accuracy of Lowry model's simulation of the real world commuting pattern.

The data for population and its forecast to 2040 can be downloaded from web site of California Department of Finance (DOF, 2003). The Demographic Research Unit of the California DOF provides the official source of demographic data for state planning and budgeting. Their data files are posted on the web site both by year and by county (http://www.dof.ca.gov/newdr/). The county data files show the population by age and ethnic groups year by year from 1970 to 2040. The raw data needs to be processed by aggregating different age groups to get the total population for each year.

CHAPTER 4

CALIFORNIA'S URBAN STRUCTURE ANALYSIS

To have a general view of California's urban system, I want to study the statewide urban structure in California before concentrating on the Central Valley study area and specific cities' consumer behavior in the study area. At first I will simulate the rank-size rule for California in 1990 and 2000, and compare it with the rank-size rule nationwide through the study of both MSA and Urbanized Area data. Then I will investigate the urban structure at different levels by applying a gravity model.

Rank-Size Rule Simulation

The rank-size rule is a rank-size relationship for a region's urban system, stating that, under ideal conditions, the size of the nth largest city is one-nth of the largest city.

$Pn = P1/n$ ---4.1

Pn is the population of the nth largest city or town.

Empirical study of the rank-size rule typically employs linear regression, using the logarithm value of rank and size and comparing the interception, slope, and R-square.

$Ln (Pn) = A – B * Ln (n)$ ---4.2

A is the logarithm value of the largest city. B is the declining rate of size with increasing of rank. If B = 1, the ideal rank-size rule can be applied to the studied urban system. If B > 1, the size decreases faster with the increase of rank than the normal case, and the size of small cities and towns is smaller than expected. It is a large city dominating urban system. If B < 1, the size decreases slower with the increase of rank than the normal case, and the size of the small cities and towns is larger than expected. It is a small city dominating urban system. In the time series, if B is increasing, it implies the force of concentration is stronger than the force of dispersion, the cities are growing faster than small cities. If B is decreasing, the force of concentration is weaker than the force of dispersion, the large cities are growing slower than small cities.

Table 4. Rank-Size Rule for USA and California in 1990 and 2000

Case	observation	A	B	R^2
MSA,CA, 1990	15, >50k	16.595	1.7651	0.9831
MSA,CA, 2000	16, >50k	16.711	1.7280	0.9897
UA, CA, 1990	38, >50k	16.267	1.4972	0.9888
UA, CA, 2000	56, >50k	16.087	1.3034	0.9900
MSA, USA, 1990	284, >50k	17.726	1.0967	0.9795
MSA USA, 2000	280, >50k	18.073	1.1457	0.9740
UA USA, 1990	396, >50k	17.508	1.1058	0.9892
UA USA, 2000	464, >50k	17.782	1.1214	0.9893

Table 4 shows the results of applying the rank-size rule on US and California's MSA and UA in 1990 and 2000 respectively. Some trends are very clear. All the regressions have high R square, ranging from 0.974 to 0.990. California's B value is larger than USA's, which indicates that California's urban system is more dominated by large cities than USA. B value for USA is close to 1, but slightly bigger than 1, which indicates USA's urban system is close to ideal rank-size situation with weak large city domination. Even through the B value for California is still higher than USA's, the B value for UA in

California decreased significantly between 1990 and 2000, which implies large city domination is declining in California . This is the common result of post industrial society, in which dispersion starts to dominate the urban process after decades of concentration.

Table 5. Population Projection for Major Central Valley Cities by Rank-Size Rule

UA Name	Population, 2000	2040	2040/2000	2100	2100/2000
Sacramento	1393498	3780134	2.71	5171224	3.71
Fresno	554923	1432403	2.58	2100170	3.78
Stockton	313392	811965	2.59	1239755	3.96
Modesto	310945	542779	1.75	852934	2.74
Bakersfield	268800	397145	1.48	638164	2.37
Antioch	139453	307677	2.21	503497	3.61
Visalia	120044	247953	2.07	412065	3.43
Merced	110483	205675	1.86	346399	3.14
Redding	105267	174409	1.66	297220	2.82
Yuba City	97645	150490	1.54	259175	2.65

Different sampling strategies for Central Valley's UA in 2000 generate different result. The general trend is that the A and B value are increasing in accord with the extension of sampling to smaller city size. Such as, the A and B value for top 21 urbanized areas with 50,000 or more population are 13.974 and 1.0557 in 2000. They increase to 14.707 and 1.3922 if the samples taken are top 110 urbanized areas with 2,000 or more population. If we assume A and B for 110 urbanized areas in Central valley are 15.145 and 1.4 in 2040, and 15.459 and 1.3 in 2100, the total urban population increase rate by rank size rule is close to DOF's forecast population increase rate for 30 counties in Central Valley area. The following table (table 5) lists the population estimation for the top 10 urbanized areas according to the assumed rank-size rule.

Rank-size rule must be used with caution. The regression treats large cities and small towns equally in sampling. The large cities are always outnumbered by small towns, and thus are under represented. The result normally shows the ideal size of large cities in accord with the rank-size rule of the small cities and towns. In the real world, some cities' rank may change over time with their economic situation and population growth rate. The forecast for the rank-size in the future can only be treated as a rough estimation.

Application of Gravity Model

The core of the Central Place Theory is to illustrate the market area of the central places. Marr (1967) found the relationship between increase in population density and the size and composition of establishments in urban places in California's San Louis Water Delivery Area. He drew the trade area by concentric circles showing limits of patronage. He also anticipated the increase of establishments with the increase of population density, and the change of trade area by competition of patronage between central places.

Newton's law of gravitation in physics was transplanted to social science and can be used in human geography to study the flow patterns of migration, traffic, passenger movements, commodity flow, and to assess the economic influence sphere of cities. Gravity force can be used to estimate the influence sphere between two adjacent cities, and the distribution of the summation of gravity forces can be used to cluster urban places into groups. The summation of gravity forces is also a useful indicator of urban pressure on adjacent rural societies.

Transplanting the law into social science function, the gravity force of a city with population Pj to a settlement i with unit population in dij km from CBD of Pj can be expressed as:

$$Fij = Pj/dij^{b}\ , \quad j = 1, 2, \ldots, n \text{ ------------------------------4.3}$$

Fij, the gravity force of Pj to i,

Pj, population of the urban center generating gravity force on its neighborhood,

dij, the distance between the urban center and the unit settlement,

b, the friction index for distance decay.

If the influence sphere for a city is defined as the area where the city's gravity force is larger than all other cities', the influence sphere for an urban system can be assigned to different cities by calculate and compare the gravity forces. The case studies of San Francisco and Sacramento, San Francisco and Concord can illustrate the application of gravity model to determine the influence sphere of urbanized areas (Figure 8, Figure 9). Linking by interstate 80, Sacramento is 120 km east of San Francisco. The population for Sacramento and San Francisco are 1,393,498 and 2,995,769 respectively. Taking the road condition into account, the friction index for distance decay should be larger than 2, if we assume the friction index is 2 for perfect road conditions. By applying the fraction index of 2.5, we expect the crossing point of gravity force to be closer to Sacramento, 69.1 km by accurate calculation. As seen in Figure 8, the crossing point is 69 km to San Francisco. Vacaville will be assign to the influences sphere of San Francisco, even through it is closer to Sacramento. Dixon and Winters will be assigned to Sacramento's influence sphere for Sacramento generates more influence on them than San Francisco does.

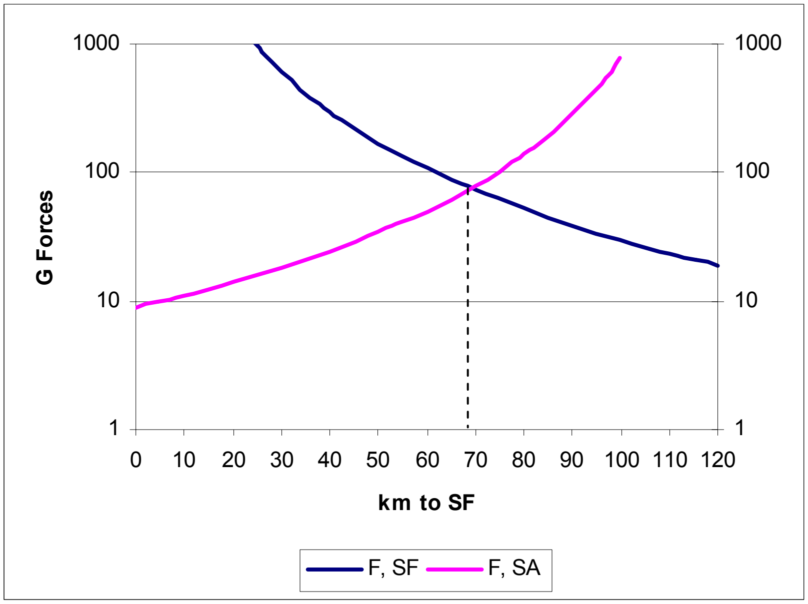


Figure 8. The Gravity Force of San Francisco and Sacramento

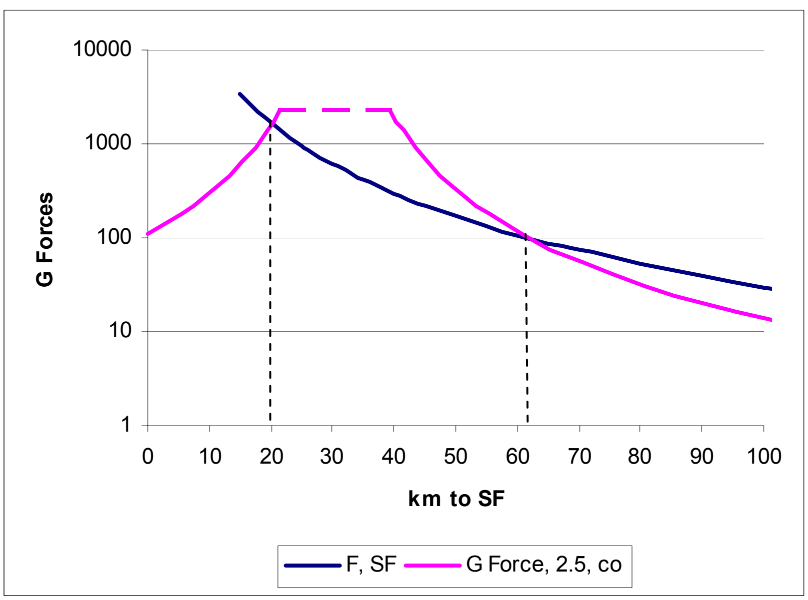


Figure 9. The Gravity Force of San Francisco and Concord

For a location in an urban system with n urban centers, the summation of the gravity forces for location i, SFi, can be called the potential of the urban system.

$SFi = \sum_{j=1,\, n} (P_j/d_{ij}^{\ b})$

For California, if i is the grids covering the whole state, and the grids will be assigned to the urbanized area which generate the largest gravity force. This GIS process can be used to calculate the influencing spheres of each urbanized area in the whole urban system.

There are four different ways to calculate the great circle distance between two points on the globe (Group editor, 1979). The most accurate one is to establish a three dimension coordinate system with the (0, 0, 0) point on the center of the earth, then calculate the length of the chord (linear distance), then calculate the length for the arc of the big circle. The next accurate method is calculating the arc directly by using function for a rectangular triangle on a globe:

$Cos\gamma = Cos\alpha\ Cos\beta$

γ is the arc of the big circle, α, β is the longitude and latitude arcs respectively. The maximum error of this method for California area is just 0.035%. This method is employed here. The third one is to treat the big arc as the chord of a rectangular triangle, the longitude and latitude arcs as the bases for the rectangle, and then calculate the linear length of the chord to approximate the big arc. The maximum error of this method for California is 0.135%. The fourth method is to use the projected coordinates to calculate the linear distance directly. The error should be the largest among the four, but it can still be employed , for the error is bearable at a statewide scale.

I used the grid cover with 3048 cells covering California and adjacent areas, and calculated the physical distance to each of the 79 urbanized areas, and then calculated the gravity force of each urbanized area to each cell by assuming b = 2.5. The large b, the steeper the distance decays of the gravity force. If the study area's urban center's populations are very close to each other, the b value is not important to determine the influence area, and can be easily assumed to be 1. Theissen's polygon only draws polygons according to physical distance to central places, it is normally not identical to the gravity model unless each central place has the same population. California has a large city dominated urban system, if b is too small, the whole state will be covered only by Los Angeles and San Francisco. I take b = 2.5 in the empirical study, for it is the smallest b value for Los Angeles to dominate the far north-east corner of California.

Finally two values are calculated for each cell, the urbanized area with the largest gravity force to this cell and the summation of the gravity forces. The assignment of urbanized areas to each cell can be used to draw influence spheres for each urbanized area, and the summation of the gravity force can be used to cluster the urbanized areas into appropriate groups by using different cutting value of the summation force.

The grid cover for California has 3048 cells, and the size for the cells is 7'30" both in latitude and longitude. Each cell is about 11.0 km by 13.9 km in California area. The cells are smaller in the north and larger in the south.

Urban Structure Analysis

The influence sphere for the 6 largest urbanized areas, with urbanized area population more than one million in 2000, shows the macro-urban systems in California (Map 2). Los Angeles dominates southern California, and San Francisco dominates northern California, the boundary of dominance is Madera in the Central Valley, about 35 km north of Fresno. Sacramento has a large influence sphere, even though its population is the smallest among the six. For Sacramento is far from San Francisco, the bulk of its hinterland is in northern California.

As the population threshold lowers to 200,000, 21 urbanized areas occur in the urban system (Map 3). Fresno influences a large territory in southern Central Valley. Bakersfield, Modesto, and Stockton hinterlands divide the southern Central Valley. The relative size of their hinterland is determined by both their population and their relative location. Stockton has much smaller hinterland than Modesto, while their populations are about the same, for some of Stockton's hinterland is taken by San Francisco and Sacramento. A more detailed urban hinterland pattern can be mapped by evaluating the top 79 urbanized areas with population more than 20,000. The grid is too large for detailed urban hinterland analysis of small cities. Some small cities have no hinterland. for they have small population and are located very close to large urbanized areas.

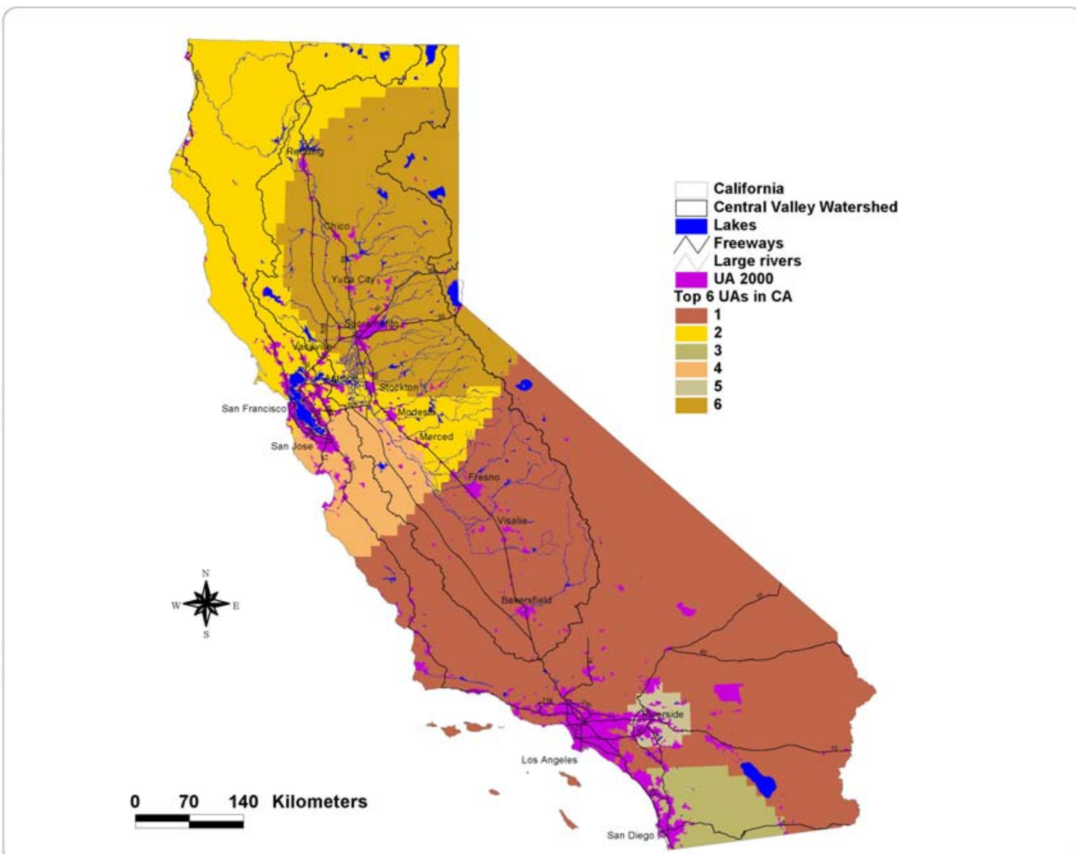
The significance of studying the urban hinterland is to simulate the migration, telephone, traffic, passenger movements, and commodity flow patterns. However, for we define the hinterland purely by gravity of population, the hinterland boundary is arbitrary. The boundary between two cities' influence sphere is flexible in the real world. Other factors may affect economic activities in the hinterland, such as the economic structure of the urbanized area and the income level of the population in the urban core. The richer the larger, the more active the economy, the larger the influence area. However, in cases economic activities are shared by more neighboring cities with one city have a largest share in an urban system, even with these limits of hinterland definition, the boundary can be used as a reference line for locating local economic activities. But it should be treated with caution and flexibility in real world applications.

Interestingly, the influence spheres for California's urbanized areas match the water resource utilization pattern very well. According the hinterland map drawn by urbanized area population in 2000, Mono Lake area is the hinterland for Los Angeles, even through it is 500 km from downtown Los Angeles. The Los Angeles aqueduct was built to derive water from the Mona Lake area and Owens Valley. It can be explained by the gravity model. With its large population, Los Angeles generates the largest gravity to the Mono Lake area. According to the gravity model, the Northern Yosemite area is San Francisco's hinterland, even through it is influenced by Sacramento, Fresno, and Los Angeles. Just as the gravity model shows, the Hetch Hetchy Aqueduct was build to supply high quality water to Bay Area. Another case of gravity and water resource utilization is San Diego and the Imperial Valley. A vigorous economy and fast population growth in San Diego has extended its influences sphere to the Imperial Valley area. The water allocation between them is another application of gravity model. Imperial Valley has the water right, but San Diego needs water. Los Angeles is another player in southern California's water allocation, for much of the Central Valley area is in its hinterland, and is a source of imported water. Los Angeles' hinterland is large enough to stretch out of California, and the down stream of Colorado River is under its influence. The Colorado

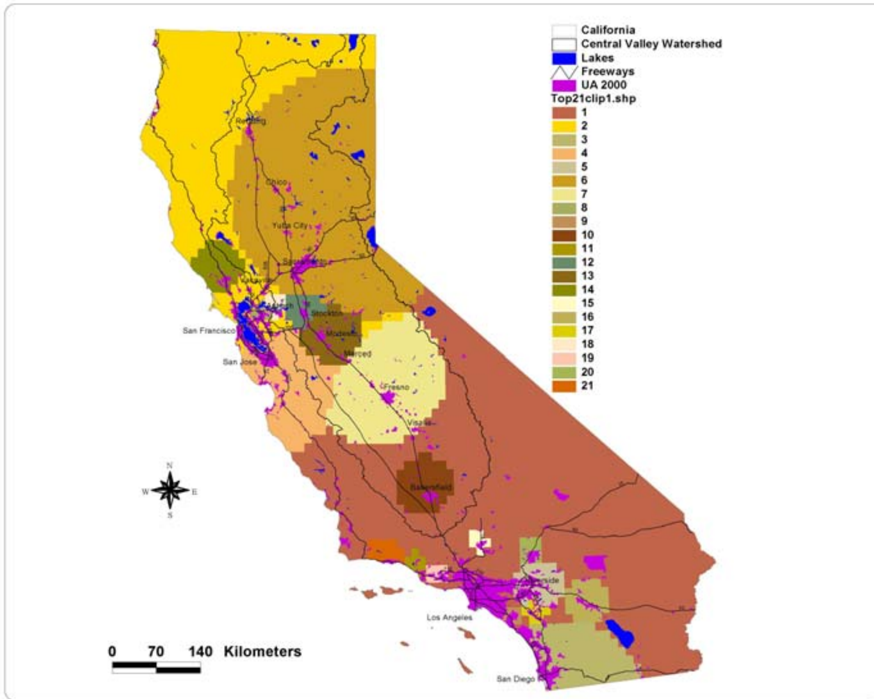
Aqueduct was built to divert water from Colorado River to supply the Greater Los Angeles Area.

If we calculate each cell's summation of gravity forces by California's largest 79 urbanized areas in 2000, and shaded the cells according to the value by graduated color from light to dark gray, we have a map shows the gravity force surface. The dark gray area has smaller gravity enforced by the urbanized areas, and is dominated by rural landscape or far away from urban influence. The light gray has larger gravity enforced by the urbanized areas, and is dominated by urban landscape or close to urban influences.

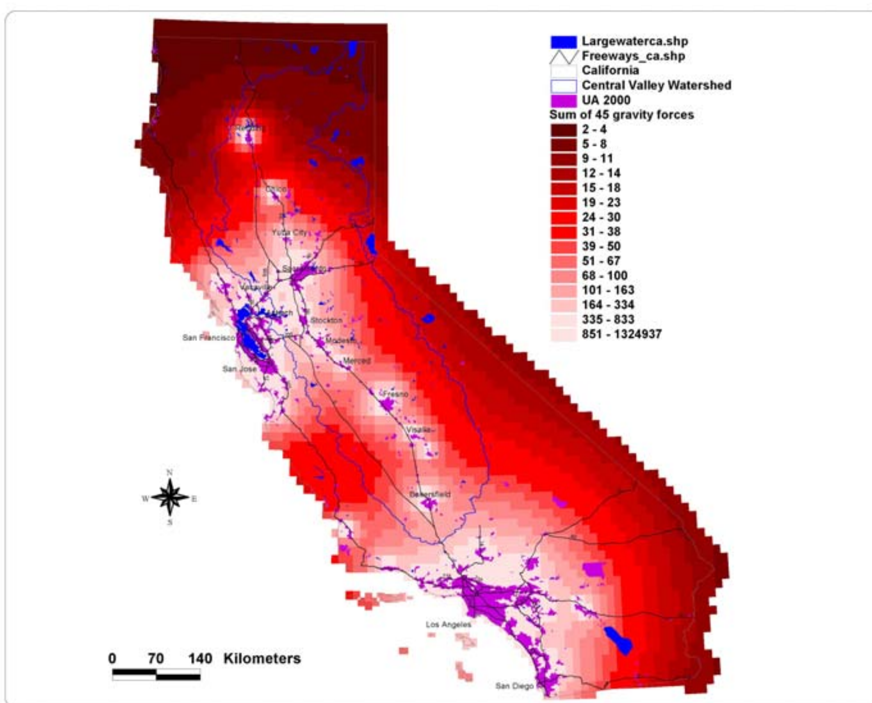
California is a post-industrial society, and the spillover effects dominate the urban fringe. The gravity force surface is actually showing each cell's tension of urban sprawl. As shown on map 4, the areas shaded light gray bare the most tension for urban expansion. They concentrate on four regions, southern California region centering on Los Angeles and San Diego, Central Coastal California centering on San Francisco and San Jose, Middle Central Valley from Sacramento to Merced, South Central Valley from Fresno to Bakersfield. The Central coastal California and Middle central valley region trend to merge together for they are very close to each other. Another application of gravity model is to cluster urbanized areas by the gravity force surface. Clustering merges small urbanized areas into large ones, and thus the urban system structure and spatial economic structure is shown clearly. By taking the hinterland of the largest 45 urbanized areas as basic unit, the distribution pattern for the aggregate gravity force of the 45 cities (Map 4) can be used to cluster the urbanized areas into 19 groups. If the urbanized area is very compact, the core areas will merge into one according to the distribution of total gravity force. The scheme to merge the influence sphere of 45 urbanized areas (with population of 60,000 or more in 2000) into 19 groups is shown in Map 5 and Map 6. Significant mergers of urbanized areas are located in Bay Area and Greater Los Angeles. Satellite urbanized areas in the near suburban of San Francisco, San Jose and Los Angeles contribute to the major urbanized areas. San Jose is merged with San Francisco, and Concord and Santa Cruz as well. Small urbanized areas at the suburb of Los Angeles are merged into the greater Los Angeles, including Riverside, Victorville and Oxnard. The Central Valley urbanized area Antioch and Vacaville is absorbed by the Bay Area. The consolidations in the Central Valley area include: Davis' hinterland is



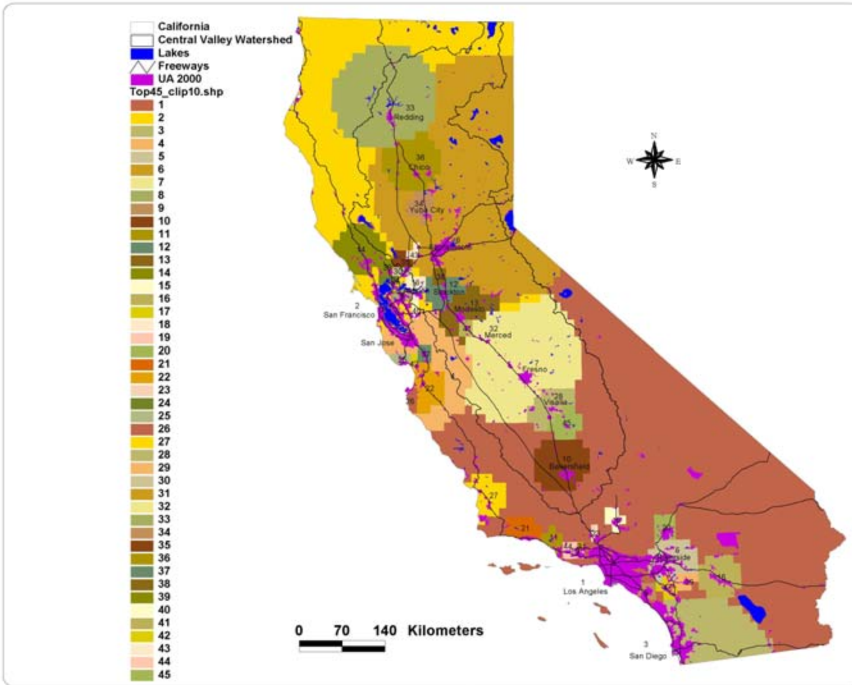
Map 2. California Urban System by Top 6 Urbanized Areas in 2000



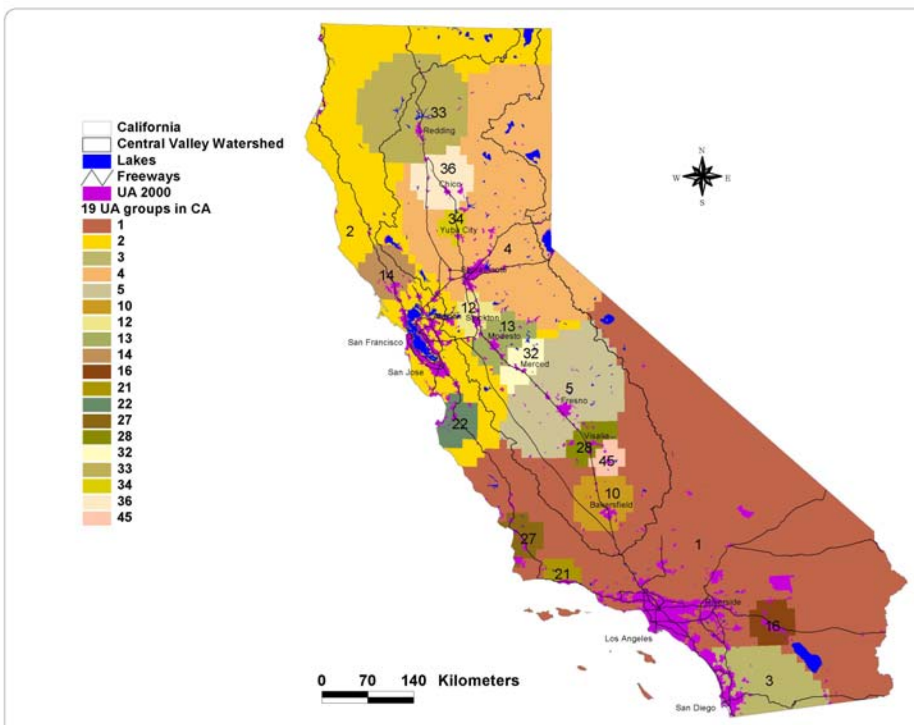
Map 3. California Urban System by Top 21 Urbanized Areas in 2000



Map 4. The Gravity Surface for Top 45 Urbanized Areas in California 2000



Map 5. California Urban System by Top 45 Urbanized Areas in 2000



Map 6. California's 19 UA Groups Clustered by Top 45 UAs in 2000

assigned to Greater Sacramento, Lodi is assigned to Stockton, and Turlock is integrated into Modesto. Other outstanding urbanized areas with their own influence sphere in the Central Valley are Redding, Chico and Yuba City in the north, and Bakersfield, Portville, Visalia, Fresno, and Merced in the south. Through eliminating small hinterlands surrounded by large ones, the differences of the total area of the hinterlands are reduced through the clustering process. The urban system is clearer than fully differentiated urbanized areas. The consolidated urbanized areas can be treated as economic zones.

Gravity surface is also useful in transportation designing and land use conversion analysis. I will mention it again later on.

CHAPTER 5

SINGLE VARIABLE MODELS

The Theoretical Result

The purpose of statistical analysis is to test the results from the theory, find relationships between key indicators, and find key parameters in the theoretical functions. In the single variable analysis, the distance to CBD (central business district), r, will be used as a universal independent variable. Through regression of dependent variables on r, concentric spatial patterns can be found. To simulate the population density curve and housing cost density curve, linear, logarithmic, exponential, or power functions are tried to fit the real world patterns in the regression. The dependent variables include income y, the housing cost as a percent of disposable income a2, disposable income z, housing cost, and commuting cost. Their relationship with r, increasing, decreasing or no relationship, are important indicators for testing theories of urban form.

Before we design the empirical model, the variable convention is defined as follow:

u: utility function

q: space token for housing, sqkm/person;

r: distance to CBD, km.

D: Population density, person/square km

P(r): Housing cost density at r, $/square km

y: Income: $/person

k(r): Commuting cost at r, $/person

$P(r)*q$: Housing cost per person at r: \$/person

z: demand for general good, \$/person

a2: Housing cost ratio: housing cost /(income –commuting cost)

a1: 1-a2

h: commuting cost rate, \$/km

An empirical utility function, housing cost density curve, and population density curve are assumed to conduct this study. The household's utility maximizing problem is:

$Max\ u(r, q) = a1 \bullet lnz(r) + a2 \bullet lnq;$ --5.1

The consumer maximize utility by selecting r and q.

$s.t.\ \ y = z + P(r) \bullet q + h \bullet r$ --5.2

Budget constraint by normalizing Pz = 1

Assume: $a1 + a2 = 1;$ ---- ---5.3

The utility function is constant return to scale

$P(r) = A1 + b1 \bullet lnr;$ --5.4

Logarithmic housing cost density curve

$D=1/q= A2 + b2 \bullet lnr;$ --5.5

Logarithmic population density curve

$k(r) = h \bullet r$ --5.6

Linear commuting cost curve

The consumer determines his q according to First Order Condition 2.3:

$\partial U/\partial z = \partial U/\partial q \,/\, P(r)$ -------------------------- 2.3

meaning the marginal utility of z divided by price of z (normalized as 1) equals marginal utility of q divided by price of q.

The consumer determines his r according to First Order Condition 2.4:

$- \partial P(r)/\partial r \bullet q = \partial k(r)/\partial r$ -------------------------- 2.4

meaning the decreasing rate of rent at r equals the increasing rate of commuting

$1.3\ \partial U/\partial z = \partial U/\partial q / P(r)$ derives

$a1/z = a2/(q \cdot P(r))$ --5.7

$1.4\ - \partial P(r)/\partial r \bullet q = \partial k(r)/\partial r$ derives

$h = q \cdot (-b1)/r$ ------------------------------------5.8

5.7 and 5.8 derives the theoretical function for z

$z = a1 \cdot q \cdot P(r) / a2$ ------------------------------------5.9

and theoretical function for commuting cost

$h \cdot r = - b1/D$ --5.10

Plug 5.9, 5.10 into budget constraint derives

$y = z + P(r) \cdot q + h \cdot r,\ a1 + a2 = 1$

$y + b1 \cdot q = P(r) \cdot q/a2$ --5.11

$a2 = P(r) \cdot q/(y + b1/D)$ --5.12

This is the theoretical function for a2.

With its logarithmic utility function, the household's utility maximizing problem has a special property for a2. u can be treated as the increasing transformation of u0:

$u0 = z^{a1} \cdot q^{a2}$, in which, $a2 = du0/u0/dq/q$----------------------------5.13

a2 is the elasticity of utility with respect to space. If a2=0.4, it means 1% increase of space can induce 0.4% increase in consumer's utility. Notice that a2 has double meanings, elasticity of utility with respect to space and housing cost ratio of disposable income. It is an interesting result for the dual explanation of a2. It states that, theoretically, if 1% increase of the item can bring the consumer 0.4% in utility increase, the consumer will spend 40% of its income on this item.

There are three steps to examine the theoretical result.

Step1: Derive D(r) and P(r) function by regressions for population density and housing cost density on r. The empirical parameter b1 value is obtained in this step.

Step 2: Calculate housing cost according from housing cost density and population density data, and calculate theoretical commuting cost by using function 5.10 and b1 derived from step 1 and empirical D value. Also calculate a2 using function 5.12, b1 and empirical P(r), q, y, and D values.

Step 3: Regress a2, y, housing cost, commuting cost, and z on r to find spatial patterns for these variables. The consumer behavior relating to distance to CBD for a specific city can be illustrated through those regressions. And the R squares of the regressions indicate the model's fitness to observed consumer behavior.

Table 6. Commuting Cost Equation for Different Population Density Functions

Density	Density functions	Commuting cost
logarithmic	P= a1 + b1*lnr; D = a2 + b2*lnr	h*r = -b1/D
exponential	lnP = a 1+ b1*r; lnD = a2 + b2*r	h*r = -r*b1*P/D
power	lnP = a1 + b1*lnr; lnD = a2 + b2*lnr	h*r = -b1*P/D

If the empirical density functions are exponential and power in form, the corresponding equation 5.10 will be different. Table 6 shows the commuting cost equation for different population density functions. The corresponding commuting cost equation for linear density function also can be derived, but will not be employed in this research, for it always fit the point poorly.

Theoretical Probe for Adding a Time Constraint

Theoretical research is conducted to include discretionary time in the utility function and add a time constraint.

Max u = U(z, q, tr(r), tl(r)), U (+, +, -, +)---------------------------*5.14*

s.t. a. y = Pz • z + P(r) • q + k(r) - Budget Constraint -------------------------*5.15*

b. 24 = tr(r) + tl(r) - time constraint---------------------*5.16*

c. tr(r)= b • r - relationship between tr and r -----------*5.17*

U(z, q, r): utility function;

z: demand for general goods; q: household land area;

y: household income; r: distance to CBD

P(r): housing cost density; k(r): commuting cost;

tr(r): commuting time; tl(r): leisure time

The +, - signs for U indicate the relationship between the variable in the utility function and the utility, + means positive relationship, - means negative relationship.

First Order Condition results are:

$$\partial U/\partial z/Pz = \partial U/\partial q / P(r) = b(\partial U/\partial tr - \partial U/\partial tl)/(q \bullet dp/dr + dk/dr), \text{----}5.18$$

The left hand side of the equation is the ratio of marginal benefit and marginal cost for z. The middle item of the equation is the ratio of marginal benefit and marginal cost for q. And the right hand side item is the ratio of marginal benefit and marginal cost for r, both nominator and dominator are negative. Combining the 2 first order conditions with 3 constrains a. b. c., we have 5 functions to solve for 5 variables z, q, r, tr, and tl, and the model can be solved theoretically. The attached Mathematics Notes Appendix shows derivation details.

Empirical Results

The result from the case study of Chico is shown in table 7. The case study is based on census data at Census Block Group (CBG) level in 2000. They are 79 observations for most of the models, while the effective observation number for z and a2 is 70.

Table 7. The Model Result for Chico by 79 CBG Observations in 2000

model	coefficient a	t value of a	coefficient b	t value of b	R^2
P-lnr	8902505.3	17.80	-3125301.2	-6.93	0.384
D-lnr	3348.07	18.20	-1515.59	-9.13	0.520
lna2-r	-0.88859	-12.63	-0.09677	-4.07	0.196
lny-lnr	9.1624	130.88	0.2877	4.56	0.212
lnP/D-lnr	7.9421	161.93	0.1373	3.10	0.111
ln(-b/D)-r	6.620556	41.17	0.348952	6.65	0.365
z -r	3898.372	4.36	1334.165	4.39	0.219

Regression 1: $P(r) = A1 + b1 \bullet \ln r$ *-------------------------5.19*

infers the housing cost density curve. The housing cost density ($/sqkm) is regressed on distance to CBD(km). A logarithmic form fits the field data much better than exponential and other form. b1 is negative as expected. The R square is 0.384, the curve fit the observations well (Figure 10).

Regression 2: D = A2 + b2•lnr --*5.20*

infers the population density curve. Field population density (persons/sqkm) is regressed on distance to CBD (km) by using logarithmic format. The R square, 0.520, is very high for single variable regression.

The following regressions are optional for other case studies. But their relationship with the distance to CBD is critical to describe characteristics of the consumer behavior.

Regression 3: lna2 = a + b•lnr ----------------------*5.21*

a2, housing cost as percentage of disposable income (%), is regressed on distance to CBD (km) by using power function. a2 increases with r in Chico. It indicates that housing space increase for the people downtown increase their utility to increase more significantly than the people in the suburb. a2 will be employed to monitor space consumption behaviors among cities with different sizes.

Regression 4: lny = a + b•lnr --------------------*5.22*

Income, y ($/person) is regressed on distance to CBD (km) by using power function. By the theory, income should increase with r, and the result confirmed it.

Regression 5: Ln (P(r)/D) = a + b•lnr --------------------------------------*5.23*

Housing cost, P(r)/D ($/person) is regressed on distance to CBD (km) by using a power function. Housing cost is a critical variable for calculating a2. The low R square shows the weak positive relationship between housing cost and distance to CBD, which indicates that the people in the suburb pay only little more for larger housing space.

Regression 6: ln(-b1/D) = a + b•lnr ----------------------------*5.24*

Commuting cost, -b1/D ($/person) is regressed on distance to CBD(km) by using a power function. Commuting cost should be increasing on r according to the theory. The result did not exactly match with the model's linear assumption: K(r) = h•r, but it does show the positive relationship between distance to CBD and commuting cost, and the relationship is close to linear.

Regression 7: lnz = a + b•lnr ----------------------------5.25

Demand for general goods, z ($/person) is regressed on distance to CBD(km) using a power function. According to the theory, z should have random distribution on r, i.e. zero relationship with r. The result did not confirm this. It shows that the demand for general goods increases with r.

The models for Chico are applied to other 14 sampled urbanized areas (Table 8). Sacramento and Fresno are the two largest cities. They are studied specially by using both 1990 and 2000 data, through which we can see the time series change of population density and housing cost density. The general trend is that the R square for housing density function is lower than the R square for population density as functions of r. If we take 0.1 as acceptable R square, four of them, Stockton, Visalia, Yuba City and Woodland have low R square for their population density function, and thus are not consistent with the model. Two of them, Bakersfield and Lodi, have low R square for the housing cost density function. Low R square or zero relationship between population density and distance to CBD is caused by three factors: 1. Compact urban development, as applies to Stockton, Visalia and Woodland; 2. the urban area is separated by physical features like river and the basic assumption is undermined, such as Yuba City, 3. a large transportation line runs through a small sized urbanized area, such as Woodland. Once the concentric zone's assumptions are disturbed, the model can not fit the field data.

Zero relationship between housing cost density function and r is caused by two factors: 1. Compact urban development, the population density has weak relationship with distance to CBD; 2. the income difference between downtown and suburb is relatively large, which drives up the relative housing cost density in the suburb. This make the housing cost density curve flat, and thus the housing cost density has random relationship with distance to CBD.

Normally the city with a larger size should fit the concentric zone model very well, but Stockton is a special case to study. A large area of commercial and services, industrial, transportation, and mixed urban land use concentrate in Stockton's CBD area, and thus the residential density is low downtown. Interstate 5 and state route 99 run parallel through Stockton, the linear development along these two freeways also makes the concentric zone model unfavorable to fit Stockton.

Finally 8 cities were modeled with acceptable R square. Descriptive analysis for four of them, Chico, Antioch, Merced, and Vacaville follows.

The population density for Chico is 1200 persons per square km in the suburb (4 km from CBD), 6000 persons per square km in downtown area. The housing cost density is 5 million dollars per square km in the suburb, 15 million dollars per square km downtown. Chico is an isolated urbanized area in the north of the Central valley. The income decreases from $15,000/person in the suburb to $5000/person in downtown. Both demand for general goods and commuting cost increases with distance to CBD. Housing cost per person is relative flat on distance to CBD, and the housing cost ratio decreases with the distance to CBD, which is caused by the high income communities in the suburb. (Figure 10)

The population density for Antioch is 1300 persons per square km in the suburb (5-6 km from CBD), 4100 persons per square km in downtown area. The housing cost density

Table 8. Original Regressions without Using Urban Area for Density Calculation

Cities	Obs.	function	a	t of a	b	t of b	R square
Antioch	37	lnD=a+b*r	8.3794	65.86	-0.3385	-5.97	0.504
	37	lnP=a+b*r	16.38	110.73	-0.2114	-3.20	0.227
Merced	50	lnD=a+b*r	9.23602	41.01	-0.35377	-4.51	0.298
	50	lnP=a+b*r	15.903	65.83	-0.26883	-3.20	0.176
Vacaville	46	lnD=a+b*r	9.29289	43.07	-0.36127	-4.25	0.291
	46	lnP=a+b*r	16.4457	66.45	-0.23399	-2.40	0.116
Chico	79	D=a+b*lnr	3348.07	18.20	-1515.59	-9.13	0.520
	79	P=a+b*lnr	8902505	17.80	-3125301	-6.93	0.384
Modesto	201	lnD=a+b*r	8.9442	66.58	-0.0923	-5.18	0.119
	201	lnP=a+b*r	15.9149	114.16	-0.0737	-3.98	0.074
Turlock	34	lnD=a+b*r	9.1471	50.10	-0.3045	-3.72	0.302
	34	lnP=a+b*r	15.7394	65.55	-0.1036	-0.96	0.028
Stockton	211	lnD=a+b*lnr	8.8899	77.88	-0.1763	-2.52	0.030
Bakersfield	215	D=a+b*lnr	8396.31	18.97	-1713.11	-6.40	0.161
Visalia	61	D=a+b*lnr	6071.41	12.26	-1091.13	-2.39	0.089
Redding	84	lnD=a+b*lnr	7.8381	25.17	-1.0683	-7.33	0.396
	84	lnP=a+b*lnr	15.8722	52.97	-1.0701	-7.63	0.415
Yuba City	26	lnD=a+b*r	8.8172	32.50	-0.1809	-1.41	0.076
Lodi	38	D=a+b*lnr	8125.32	11.29	-2558.82	-3.10	0.211
Hanford	39	D=a+b*lnr	3608.25	10.12	-1065.95	-2.85	0.180
	39	P=a+b*lnr	4303190	8.25	-1601503	-2.93	0.188
Woodland	26	lnD=a+b*r	9.076	34.27	-0.2661	-1.50	0.085
Delano	12	D=a+b*lnr	2609.87	14.47	-1061.93	-4.93	0.709
	12	P=a+b*lnr	4735688	9.98	-1960904	-3.46	0.545

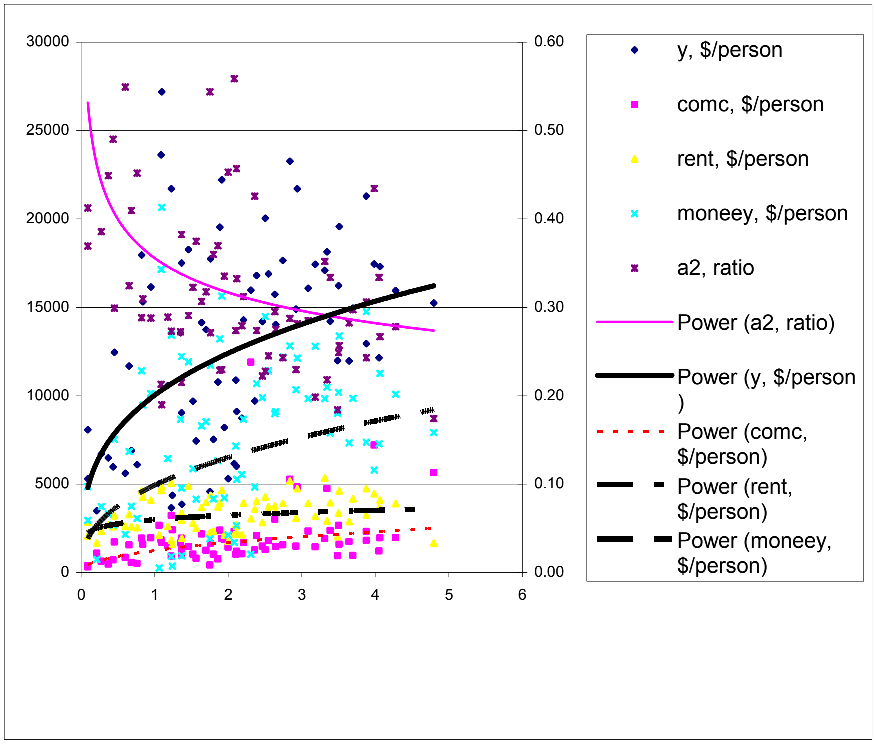


Figure 10. The Consumer Consumption Profile for Chico

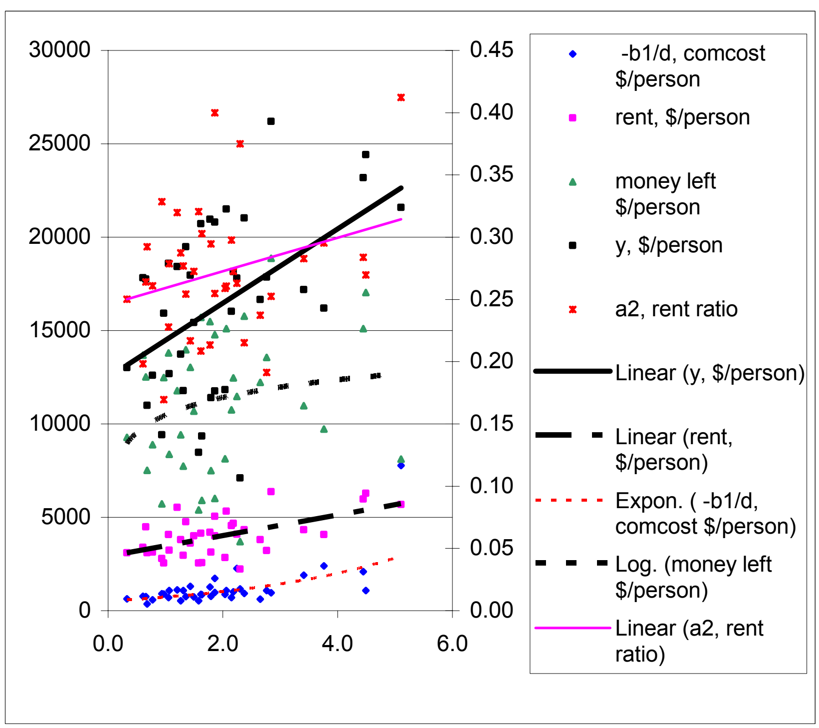


Figure 11. The Consumer Consumption Profile for Antioch

is 7 million dollars per square km in the suburb, 13 million dollars per square km in downtown. Antioch is the spillover community of the Bay Area. The income ($14,000 to $22,000 per person) is higher than Chico. All income per person, demand for general goods per person, housing cost, commuting cost and housing cost ratio increases with distance to CBD. (Figure 11)

Consumer behavior for Merced is similar to Chico. The population density for Merced is 1000 persons per square km in the suburb (5 km from CBD), 4000 persons per square km downtown. The housing cost density is 3 million dollars per square km in the suburb, 10 million dollars per square km in downtown. Income decrease from $16,000/person in the suburb to $7000/person in downtown. Both demand for general goods and commuting cost increase with distance to CBD. Housing cost per person is relative flat with distance to CBD, and the housing cost ratio increase slightly with the distance to CBD, which is caused by the high income differences between the CBD and the suburb. (Figure 12)

Vacaville is also a spillover urbanized area of the Bay area, and its consumer behavior is similar to Antioch. The population density for Vacaville is 1000 persons per square km in the suburb (4 km from CBD), 4000 persons per square km downtown. The housing cost density is 5 million dollars per square km in the suburb, 13 million dollars per square km in downtown. The income ranges from $14,000 to $25,000 per person. All income per person, demand for general goods per person, housing cost, commuting cost and housing cost ratio is increasing with distance to CBD linearly. (Figure 13).

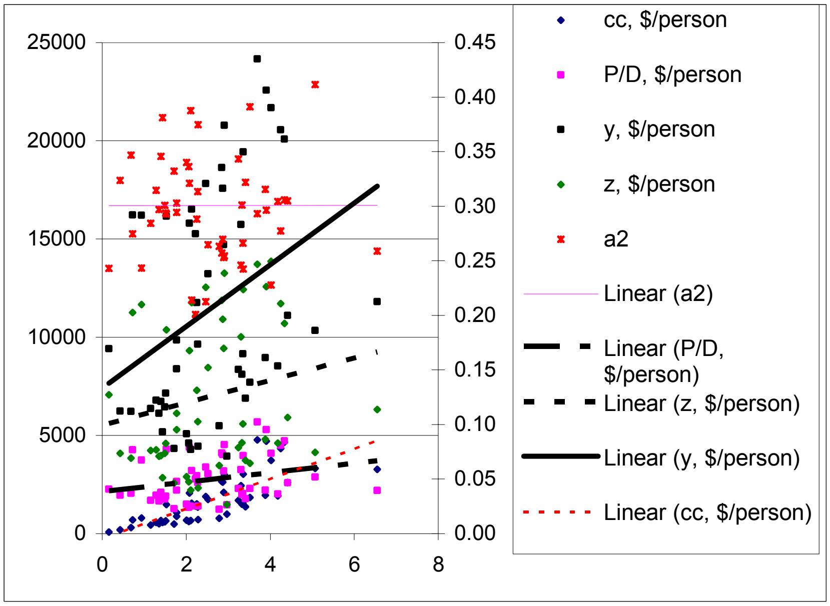


Figure 12. The Consumer Consumption Profile for Merced

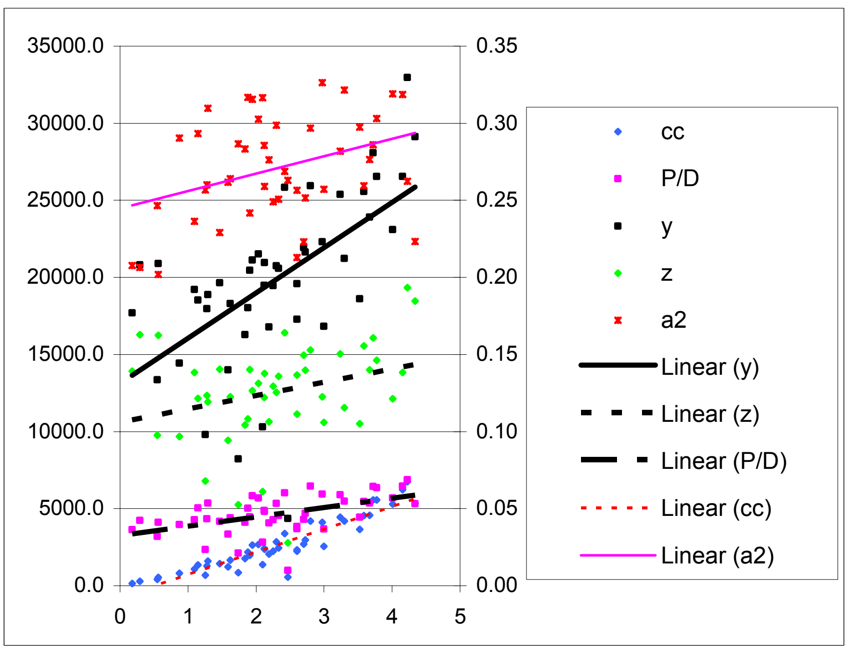


Figure 13. The Consumer Consumption Profile for Vacaville

Using total area for density calculations is not a perfect choice, for it may not reflect the real density in urban area, and the housing cost density is under-estimated. However, for leap frog development in the urban fringe, once part of the tract is urbanized, agricultural activity may be undermined in the whole tract. Vacant land today also may become a local recreational park and not be developed in the future. If a large census tract with very low population density in the urban fringe is eliminated, and we only take tracts which are mostly urbanized in the modeling, the model still make sense.

Table 9. Results for 7 Cities after Applying Urban Area in Density Calculation

Cities,2000	Obs CBG	function	R square original	R square new	notes
Antioch	37	lnDu-r	0.504	0.366	
Antioch	37	lnPu-r	0.227	0.191	
Bakersfield	226	Du-lnr	0.161	0.162	P random on r
Chico	79	Du-lnr	0.520	0.497	
Chico	79	Pu-lnr	0.384	0.327	
Delano	12	Du-lnr	0.709	0.699	
Delano	12	lnPu-r	0.545	0.631	y declining on r
Lodi	38	Du-lnr	0.211	0.156	
Lodi	38	Pu-lnr	0.000	0.120	
Redding	84	lnDu-lnr	0.396	0.236	
Redding	84	lnPu-lnr	0.415	0.266	
Visalia	61	Du-lnr	0.089	0.171	
Visalia	61	Pu-r	0.000	0.180	

To eliminate the shortcoming of using the total area for calculating population and housing cost density for the tracts or CBGs in the urban fringe, an improvement is made to use the urban area in the tract or CBGs for density calculation. Sacramento and Fresno are large urbanized areas, the tracts studied are mostly fully urbanized, and thus do not need density recalculation. The result for the other sampled 7 cities after applying urbanized area in density calculation is shown as table 9.

Compared with the original models, some housing cost density model's R squares are improved significantly, while a few of them turn worse. The R squares for Stockton, Woodland and Yuba City are still low even using urbanized area for density calculation, for their densities are close to a random spatial distribution.

To probe the effect of different population densities on the model's fitness, five largest urban areas in the Central Valley (Sacramento, Fresno, Stockton Modesto, and Bakersfield) are studied at tract level by using Census data in 2000. Three densities are calculated for each tract. They are population density by total tract area, population density by urban area in tract, and population density by residential urban area in tract. Three densities are plotted by the tract's distance to CBD in one figure for each city. The exponential functions for three population densities with R square are listed on each figure with density by total tract area on top, followed by density by urban area and residential area (Figure 14, 15, 16, 17, and 18). The population density by total tract area always has the highest R square, for the marginal tracts have very low density, which make the curve fit the data best. Population density by residential area has higher R square than density by urban area in tract at most of the cases. The residential density is always higher than urban area density, especial in the downtown area, where commercial land use takes large portion of land.

The purpose of descriptive analysis is to explain consumer behavior through empirical study, and compare the empirical result with the theory. As shown in the case study of Chico, Merced, Antioch, and Vacaville, the theory is approximately confirmed by empirical data. Most of the assumptions are confirmed by regression. Some of them have high R square, which indicates the relationship is strong and reliable. Such as the housing cost curve, density curve, and a2 function. The double meanings of a2 (space elasticity and housing cost ratio) and high R-square of a2's regression on r confirm that the model is basically acceptable.

Some theoretical results are only partial confirmed. In the theoretical model, the demand for general goods z should be constant with respect to distance to CBD for the high income is used to buy more space and pay commuting fee. The real world data in all four cases shows z has positive relationship with r, i.e. the rich did not use all their extra income to get more space. The regression confirms that the rich live in the suburb, the suburban consumers pay more commuting cost, and the rich rent more space. The increasing demand for general goods on r can be modeled by adding more items in the utility function, such as time spent in commuting is added in the theoretical probe part of this chapter. Money spending on recreation and luxury good such as open space consumption might cause suburban people to have more demand for general goods. Normal goods also have different price levels, such as cars, electronics, and furniture, the rich people tend to buy more expensive goods. Modeling consumer behavior is a complex task, for each consumer has their own preferences, and some of them do not have a spatial pattern. Alonso's household general equilibrium model can explain the spatial related consumer behavior; it is good enough to act as an economic theory base for concentric zone model, even through the model can not catch more detailed consumer behavior.

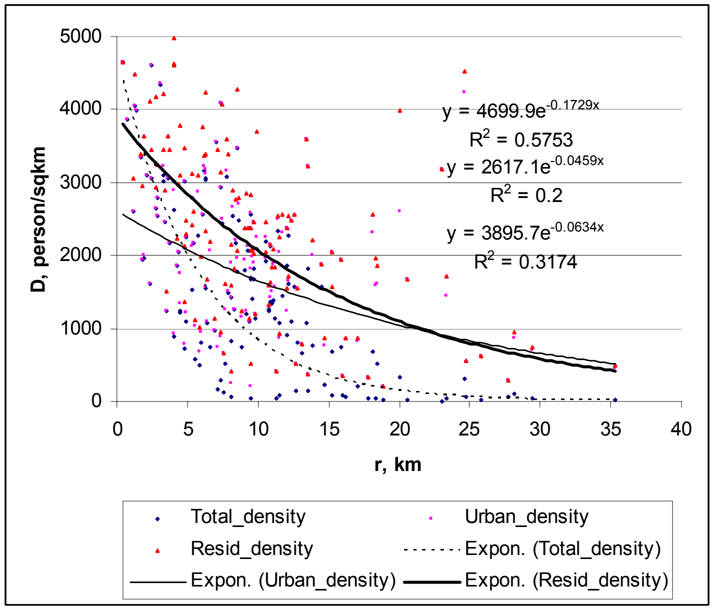


Figure 14. Three population density profiles for Fresno

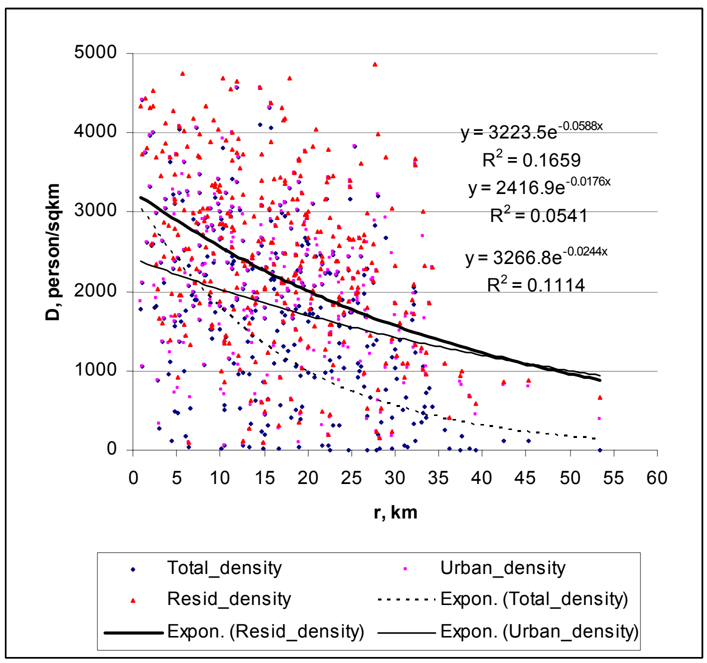


Figure 15. Three population density profiles for Sacramento

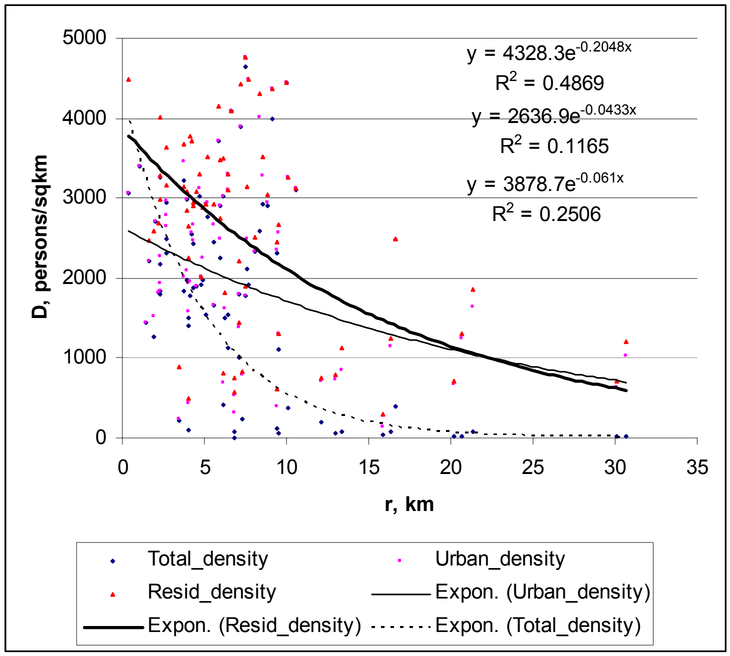


Figure 16. Three population density profiles for Stockton

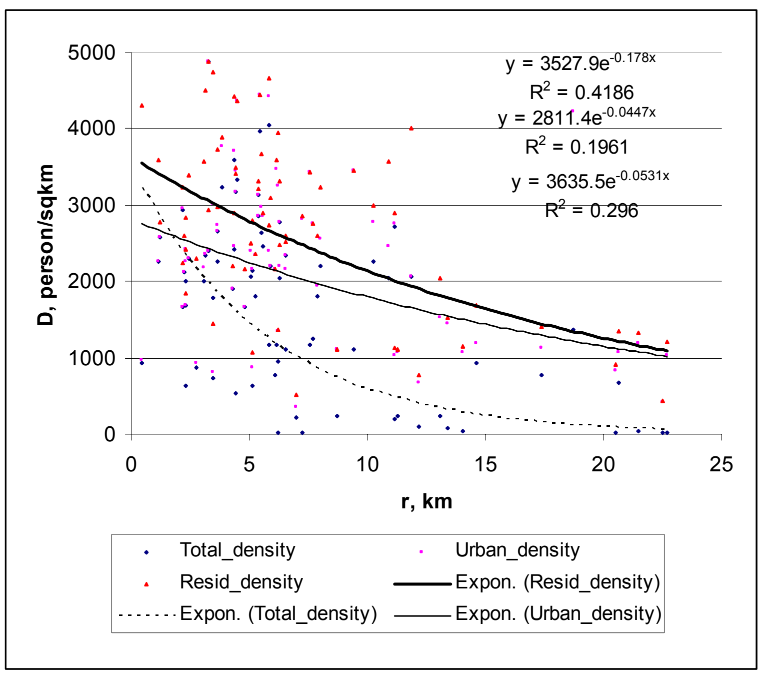


Figure 17. Three population density profiles for Modesto

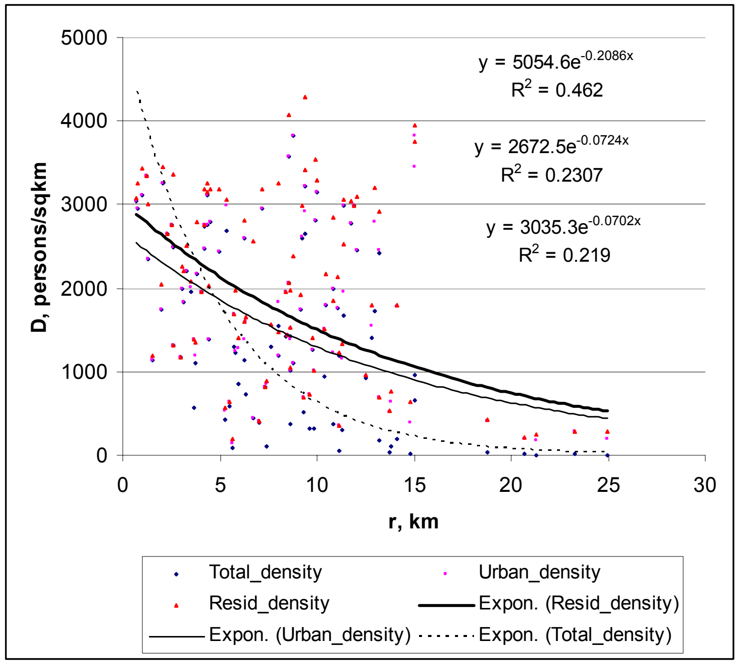


Figure 18. Three population density profiles for Bakersfield

Time Series Trends Analysis

To study the time series evolution of the consumer behavior, Sacramento and Fresno are studied at the census tract level to find the time series evolution of the consumer behavior between 1990 and 2000. The results are list in Table 10. The observations for Sacramento are 296 and 217 census tracts in 2000 and 1990 respectively. The observations for Fresno are 124 and 90 census tracts in 2000 and 1990 respectively.

Through comparison with the census block group level study for these two cities, some basic principles can be found. The model built by tract always has larger r square than by census block group. The landscape is not homogeneous. The smaller is the basic unit, the more diversity exists among the study units. The environmental noise is reduced at tract level, and thus the R square increased.

The time series evolution of the curves is also found through the case study (Figure 19). Sacramento's population density (D) is flatter in 2000 than 1990. The population density for Sacramento encountered weak decline in downtown area and strong percentage growth in the urban fringe between 1990 and 2000. The housing cost density (P) also becomes flatter. The housing cost density downtown increased less than urban fringe during 1990s.

Table 10. Time Series Comparison of Different Model for Sacramento and Fresno

Cities	year	function	a	t of a	b	t of b	R^2
Sacramento	2000	D=a+b*lnr	3217.852	17.16	-520.554	-7.10	0.146
	2000	P=a+b*lnr	10940611.9	14.29	-1389436	-4.64	0.068
	1990	lnD=a+b*r	7.944606	58.82	-0.06243	-7.19	0.194
	1990	lnP=a+b*r	15.74664	106.02	-0.05221	-5.47	0.122
Fresno	2000	lnD=a+b*r	8.41824	48.91	-0.16422	-8.73	0.385
	2000	lnP=a+b*r	15.70502	73.31	-0.07588	-3.24	0.079
	1990	lnD=a+b*r	8.507268	39.05	-0.20982	-7.96	0.419
	1990	lnP=a+b*r	15.71468	59.10	-0.14468	-4.50	0.187

During the 990s, Sacramento's income increased, commuting cost decreased, housing cost is increased weakly, demand for general goods (z) increased, and housing cost ratio (a2) decreased. The spatial pattern in 2000 fits better with the theoretical result than in 1990, such as both z and a2 becomes flatter in 2000. Income difference is larger between downtown and suburb in 2000 than in 1990.

The trend for population density and housing cost density curves for Fresno is the same as Sacramento's. During the 1990s, Fresno's income, commuting cost, housing cost, and disposable income are increased, while the housing cost ratio (a2) decreased. In

2000, Fresno's housing cost ratio curve is close to a horizontal line, with a2 equals 29% regardless there distance to CBD.

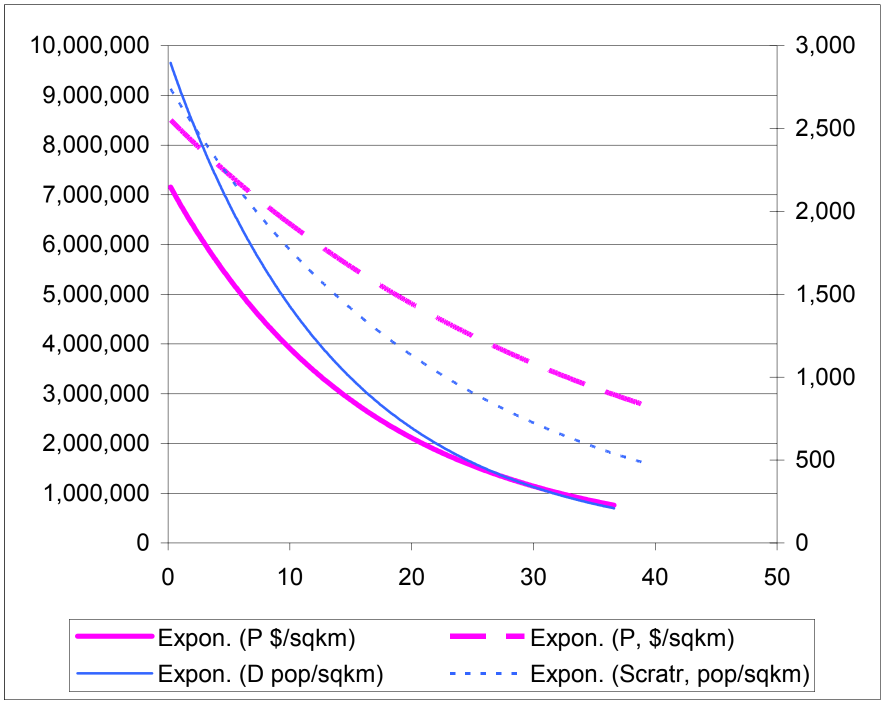


Figure 19. Time Series Evolution of Sacramento's Population Density (thin) and Housing Cost Density (thick) Curves, 1990-2000

Through both case studies of Sacramento and Fresno, we conclude that the overall population densities in these two cities are increasing. This result is important for forecasting future land use conversion in Chapter 9. The higher density can save agricultural land converting to urban usage in the urban fringe, which means that the land is used more efficiently.

Through the single variable analysis in this chapter, two conclusions can be drawn. One is that Alonso's household general equilibrium model is basically confirmed. The rich people trends to take larger space in the suburban, and thus the rich is the main pushing factor for urban sprawl. This is consistent with the amenity factor argument in the post-industrial society. Everybody wants amenity in their backyard. Another conclusion is that the consumer behavior various tremendously among different urbanized areas. The different shape of the population density curve and housing cost density curve for different urbanized areas illustrate the diversity of human behavior. The housing cost density curve normally has less R square, for the housing payment behavior needs more assumptions in the model than the population density model. The consumer behavior is harder to simulate than the population density. One unexpected finding in the single variable modeling is that the rich do not used all their extra money on housing for larger space to live. The disposable income is still higher in the suburb after the housing and transportation cost payment. This result implies that the rich people's spending on the goods other than housing and transportation is higher than the poor. The population density in Sacramento and Fresno are increasing over time. The result illustrates the fact that density accumulation dominates Central Valley's urban process, for the urbanized area is not large enough for the urban core population density decrease.

CHAPTER 6

MULTIVARIABLE MODELS

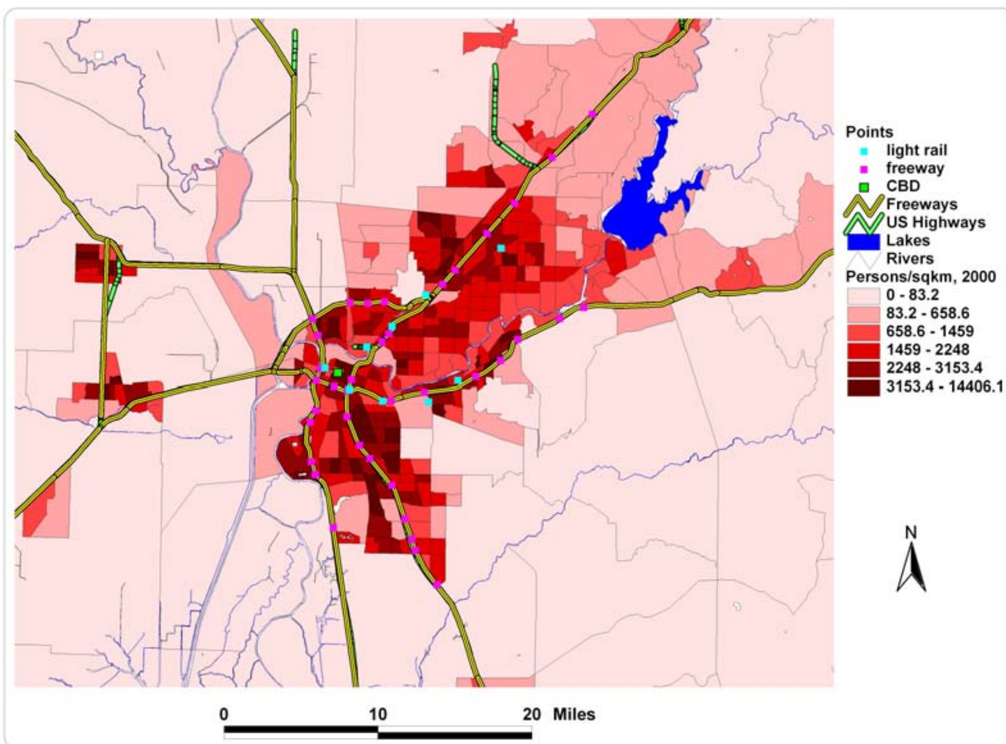
Multivariable Model for Sacramento

Just as the railroad net work and freezer freight car extended the Thunen's ring to national or even worldwide scales in the 19^{th} century, the development of highway system and interstate system in the past decades has modified the concentric zones of Alonso's model dramatically. Mean while, the suburbanization of business and industry has created employment in the urban fringe. The CBD is no longer the single factor shaping the urban landscape. The convenient transportation advantage of highway intersections in the urban fringe had attracted new business, and they can be treated as new urban centers. Light rail creates opportunities for rapid mass transportation for large cities, and thus may be factors affecting household general equilibrium budgets, and thus shape the urban social landscape. Fortunately, the concentric zone model can be modified to reflect these new situations without losing the general ideas of Alonso's household general equilibrium model. If the mono-centric assumption is relaxed, the consumer will treat interstate access and suburban centers as their new CBD, and try to find housing close to these points, and also they are ready to trade off space consumption with distance to these points. The model is represented by many variables (the distances to those points) now instead of just one factor (distance to CBD).

The low R square in applying the household general equilibrium model for some cities indicates the shortcoming of the model and single independent variable regression. Transportation is the key factor affecting urban land use in the MEPLAN model (Rodier, 2002). By taking major transportation facilities into consideration, a multivariable model for population density function relaxes the original single variable assumption. It can also adjust the physical factors (natural amenity or obstacle) by dummy variable. Multivariable models for Sacramento and Fresno, two largest cities in the Central Valley, are studied at the census tract level.

The American River runs through Sacramento, and creates a chain of low population density tracts. This factor can be represented by introducing a dummy variable. We assign 1 for the dummy if the tract is partial occupied by river bed, and assign 0 for all other tracts. Light rail tracks run from downtown Sacramento to the northeast and east. The tracks create convenient commuting for low income residents, and thus the distance to major light rail stations is taken as a variable for multivariable modeling on Sacramento. The interstate highway network is well developed for Sacramento area. The freeway network generates linear urban growth along the freeway routes. The distance to major freeway accesses is taken as a variable to represent the effects of freeways on the urban density pattern. Citrus Heights is an edge city lying on the northeast of Sacramento, the distance to Citrus Heights is taken as another variable to represent sub-center effects. The spatial patterns of population density and related physical factors in Sacramento are shown in Map 7. Finally, we have five independent variables for the multivariable analysis of Sacramento including the formal single variable(distance to CBD): 1. distance to CBD, 2. distance to light rail stations, 3. distance to major free way accesses, 4. distance to Citrus Heights (edge city effects), 5. American river bed dummy (negative)

Other factors, include a flood plain dummy variable for West Sacramento, lakeshore dummy variable for Folsom Lake, and military airbase dummy variable for the military airport located on the urban fringe of Sacramento can also be taken into account to improve model fit. However, many explanatory independent variables are not necessary for the basic ideas of modeling household decisions. The degree of freedom will also be reduced if too many variables are included in the model. To make a more meaningful explanation for consumer behavior, low t-statistic value variables will be eliminated from the model.



Map 7. Physical and Economic Settings for Sacramento Urbanized Area

The multivariable model for population density in urbanized areas for Sacramento at tract level takes an exponential form. The regression result appears in table 11. Note that the distance to light rail stations is dropped off from the model for its low t-value.

$$D = e^{a} \cdot e^{b1 \cdot r1} \cdot e^{b2 \cdot r2} \cdot e^{b3 \cdot r3} \cdot e^{b4 \cdot r4} \quad \text{---} 6.1$$

$$\ln D = a + b1 \cdot r1 + b2 \cdot r2 + b3 \cdot r3 + b4 \cdot r4 \quad \text{-----------------------------} 6.2$$

D: population density in urbanized area by tract, persons/sqkm

r1: distance to CBD, km

r2: distance to Citrus Height, km

r3: dummy value, 1 if the tract covers the American river bed, 0 otherwise,

r4: distance to closest interstate highway access, km

The multivariable model for housing cost density in urbanized areas by tract for Sacramento also has an exponential form. The regression result is shown in table 12.

$$P = e^{a} \cdot e^{b1 \cdot r1} \cdot e^{b2 \cdot r2} \cdot e^{b3 \cdot r3} \cdot e^{b4 \cdot r4} \cdot e^{b5 \cdot r5} \text{--} 6.3$$

$$\ln P = a + b1 \cdot r1 + b2 \cdot r2 + b3 \cdot r3 + b4 \cdot r4 + b5 \cdot r5 \quad \text{-------------------} 6.4$$

P: housing cost density in urbanized area by tract, \$/sqkm

r1: distance to CBD, km

r2: distance to Citrus Height, km

r3: distance to closest light rail station, km

r4: dummy value, 1 if the tract covers the American river bed, 0 otherwise

r5: distance to closest freeway access, km

In the population density model, the high absolute value of coefficient for distance to freeway access indicates the population density declines fast in accord with the distance to freeway access. Comparatively the coefficient for distance to CBD and Citrus Heights is lower, and thus population density declines slower in accord with the distance to these two points. The coefficient for dummy shows that the population density is just 58.36% of normal if part of the tract includes river bed. The coefficient and the t-value for distance to Citrus Heights are close to the CBD's, which means the effect of the Citrus Heights on the population density is significant and compares with the effects of the CBD. The rank of the t-value for factors affecting the population density of Sacramento in decreasing sequence is distance to freeway access, the American river bed dummy, distance to CBD, and distance to Citrus Heights.

Table 11. Multivariable Model for Population Density of Sacramento in 2000

lnD	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	8.2252	0.1300	63.28	0.0000
D_cbd	-0.0138	0.0056	-2.46	0.0145
D_citht	-0.0109	0.0046	-2.38	0.0178
dummy	-0.5836	0.1406	-4.15	0.0000
D_freeway	-0.1126	0.0230	-4.90	0.0000
R Square	0.1993	Observations	296	

For the housing cost density model, the interesting result is the positive relationship between distance to light rail in the multivariable model and housing cost density. The poor people trends to live close to light rail line, and thus reduce the housing cost density down. The different t-value for distance to freeway access, CBD and Citrus Height indicates the access to freeway access is the most important factor. The different coefficients indicate the different decrease rate with distance to those factors. The ranking of the coefficient value is the same as in the population density model.

Table 12. Multivariable Model for Housing Cost Density of Sacramento in 2000

lnP	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	16.8020	0.2718	61.81	0.0000
dcbd	-0.0553	0.0216	-2.56	0.0110
dcitht	-0.0305	0.0099	-3.07	0.0024
dlr	0.0822	0.0288	2.85	0.0046
dummy	-0.5243	0.1583	-3.31	0.0010
dfreeway	-0.1250	0.0265	-4.72	0.0000
R Square	0.1189	Observations	296	

Multivariable Model for Fresno

Fresno does not have a light rail system, while its freeway system is well developed. The distance to major freeway accesses is calculated as a second variable after the distance to CBD. Fresno is relative homogenous in land features, and thus no dummy variable is needed in modeling Fresno's population density and housing cost density (Map 8).

The multivariable model for population density in urbanized areas for Fresno at the tract level is:

$$D = e^{a} \cdot e^{b1 \cdot r1} \cdot e^{b2 \cdot r2} \text{ --- } 6.5$$

$$\ln D = a + b1 \cdot r1 + b2 \cdot r2 \text{ -- } 6.6$$

D: population density in urbanized area by tract, persons/sqkm

r1: distance to closest interstate highway access, km

r2: distance to CBD, km

The multivariable model for housing cost density in urbanized areas for Fresno at the tract level is:

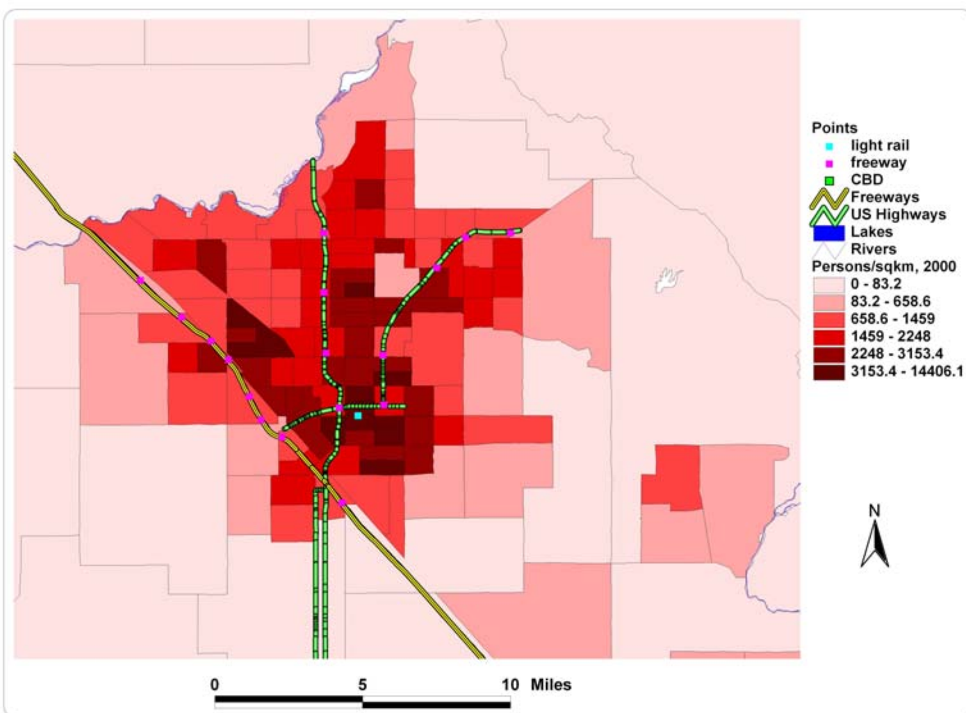
$P= e^{a}\cdot e^{b1\cdot r1}\cdot e^{b2\cdot r2}$ ---6.7

$lnP = a + b1\cdot r1+ b2\cdot r2$ -----------------------------------6.8

P: housing cost density in urbanized area by tract, \$/sqkm

r1: distance to closest interstate highway access, km

r2: distance to CBD, km



Map 8. Physical and Economic Settings for Fresno Urbanized Area

The result for population density shows that distance to freeway access is more important than the distance to the CBD in determining the decline of population density with respect to distance (Table 13). The absolute coefficient value for distance to freeway access is much higher than the distance to the CBD.

Table 13. Multivariable Model for Population Density of Fresno in 2000

lnD	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	8.0859	0.1074	75.30	0.0000
d-itst	-0.1278	0.0266	-4.80	0.0000
d-cbd	-0.0416	0.0144	-2.88	0.0047
R Square	0.3717	Observations	120	

Table 14. Multivariable Model for Housing Cost Density of Fresno in 2000

lnP	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	15.4023	0.1382	111.47	0.0000
d-itst	-0.1729	0.0343	-5.05	0.0000
d-cbd	0.0549	0.0186	2.96	0.0037
R Square	0.178866	Observations	120	

In the housing cost density model, the higher absolute value of coefficient and t-value for distance to freeway access demonstrates that the Alonso's theory is acceptable in general. People are actually trading off distance to freeway access and living space. The positive coefficient value for distance to CBD indicates the concentration of poor people in the CBD area reduced housing cost density downtown (Table 14). Another explanation for the positive value of coefficient for distance to the CBD in the housing cost density model is the concentration of commercial and industrial land use in the CBD. The commercial and industrial land are aggregated in the total area for housing cost density calculation, and thus the calculated housing cost density for CBD is lower than the actual field value. If a detailed land use map is available for urbanized areas, and if the commercial and industrial land areas are subtracted from the total land area, the coefficient may change sign.

The Intra-Urban Multivariable Models

The relationship between the size of the urbanized area and its population density can illustrate the other variable determining population density in an urbanized area. For California, the size-density relationship is poor for urbanized areas with population less than 200,000 in 2000, while obvious positive relationships between them can be found at the larger urbanized area category. For the 18 largest urbanized area in California 2000, the population density has strong positive linear relationship with the natural logarithm value of its population, the R square is as high as 0.634 (Figure 20).

There are 11 urbanized areas in Central Valley with populations more than 89,000 in 2000. Sacramento's urbanized area is disturbed by the American River and Sacramento River. Redding has an extremely scattered urbanized area. These two are outliers in the 11 urbanized areas. Strong positive relationships between urbanized area population density and natural logarithm of its population size can be found for the other 9 urbanized areas with R square equals 0.674 (Figure 21).

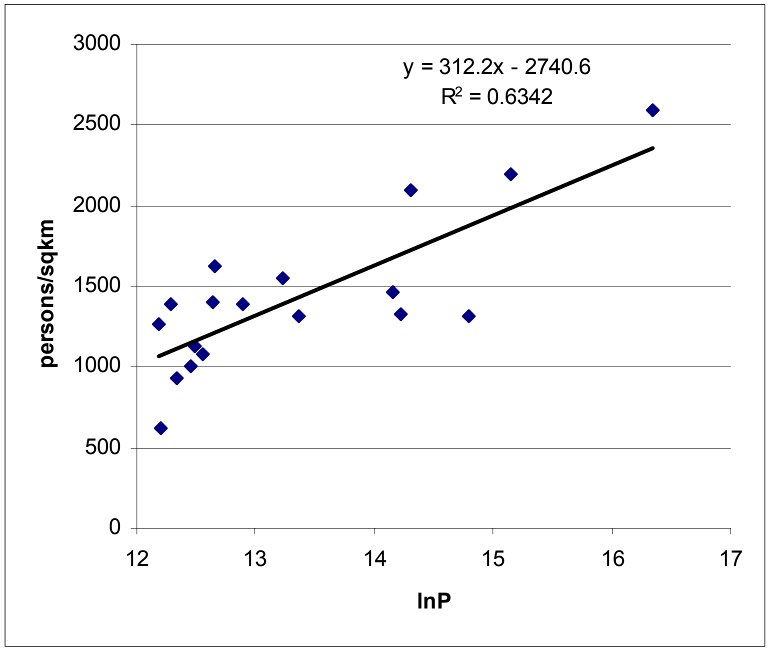


Figure 20. Urban Population Density and Urbanized Area Size in California 2000

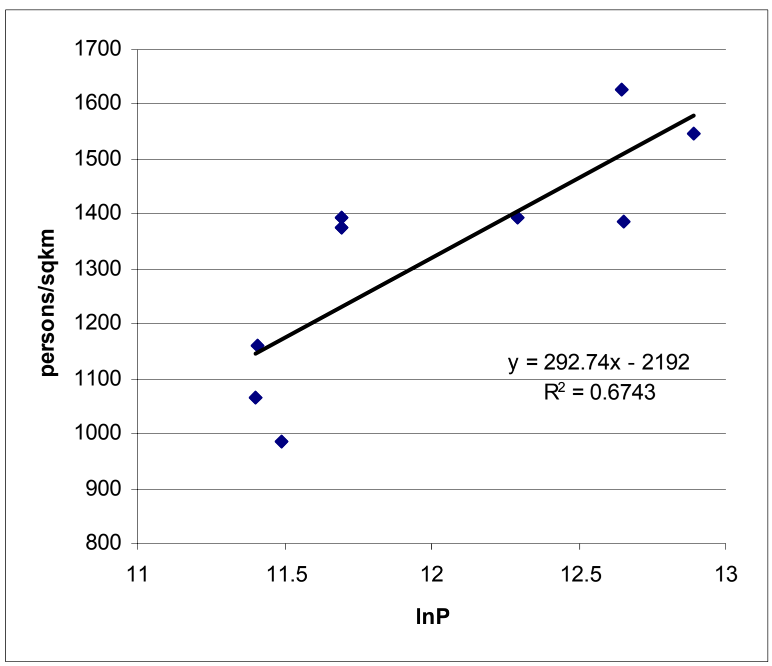


Figure 21. Urban Population Density and Urbanized Area Size in Central Valley 2000

The positive relationship between population density and urbanized area size for cities with a larger population can be explained as when an urbanized area grows to a larger size, the high population density core accumulates population, and thus raises the average population density for the whole urbanized area. This illustrates the scale efficiency of urbanized areas. We can conclude through the above results that the urbanized area's efficiency in terms of land use increases with the size of the urbanized area. Urban population growth increases urbanized area and tends to have higher average population density, reducing land use per capita. Population size is not the only factor determining the overall population density of an urbanized area. Land price and consumer behavior are other factors affecting population density for urbanized areas. The relationship between urbanized area, population density, population size, and the background land value will be investigated in detail in Chapter 8.

CHAPTER 7

LOWRY MODEL

Theoretical Bases

The Lowry model has two parts: the economic base theory and gravity model. The economic base theory can be used to calculate the service population and total population, and the gravity model is employed to settle the service employment and total population in different location given the distribution of base employment. The gravity model links the Lowry model and Alonso's theory. The gravity model assumes population density declines with the distance to the employment center. It is similar to the household's trade off between distance and space in Alonso's model. The difference is that gravity model assumes the population density curves are in the same shape for different employment centers, and it is applied to employment centers all over the study area, while the concentric model just takes CBD as a single employment center.

The choice of zip code as basic study unit is determined by the size of the unit and availability of the data. More detailed basic economic units lead to more accurate forecasts. But when the basic unit is too small, the basic employments for many of study units are zero or close to zero. Census block and census block groups are too small units to apply a Lowry model for large cities like Sacramento and Fresno. Census tract may fit Fresno, but it is still too small for Sacramento. The most detailed employment data by working location available is the US Economic Census for 1997 by 5-digits zip code. One zip code typically covers several census tracts, and is the idea unit for Lowry Model.

I used 5-digits zip code for those two cities in my study. Sacramento has 72 basic units, and Fresno has 8.

The economic base theory (Andrews, 1953) states: 1. for a city, the total population is proportional to the total employment with a constant dependent ratio, f. 2. The employment can be divided into two categories, basic (for export) and nonbasic (for domestic, or service) sectors. 3. The demand for service employment is determined by local population and service demand ratio, a. 4. If the basic employment is given, the city's population, service employment, and total employment can be forecasted. This results in a system of three variables in three equations.

$P = f \cdot E, f > 1$ --7.1

It is the relationship between total population and total employment.

$E = Es + Eb$ --7.2

Total employment is decomposed into service and basic employment.

$Es = a \cdot P, 0<a<1$ ---7.3

It is the relationship between total service employment and total population.

f :dependent ratio(given),

a: population and service demand ratio(given),

P: Population (unknown),

E: total employment(unknown),

Eb: Basic employment (known),

Es: service employment(unknown),

The result of solving for E, Es, P by Eb:

$Es = a \cdot f \cdot Eb/(1-a \cdot f)$ --7.4

$E = Eb/(1-a \cdot f)$ --7.5

$P = f \cdot Eb/(1-a \cdot f)$ ---7.6

Our purpose is to use census data to calculate a and f for the urbanized area overall, and then according to the distribution of basic employment and gravity model to allocate the population and service recursively to different zip codes. After several rounds of recursive process, the sum of population and employment allocated to each zip code should be very close to the total population calculated by the function above (Yang, 1997). Finally we can compare the estimated population, service employment, total employment and commuting time distribution with the real pattern. Once the relationship is establish with a large R square, it can be used to forecast future population, employment, and their distribution. The result can also be used as an indicator of similarity between theoretical result and real world pattern.

Steps to Apply Lowry Model

Several steps are needed to build a Lowry model.

Step 1: prepare data.

1.a Download employment, service employment, basic employment data by working location from Commercial Census 1997 data base, download population, employment, service employment, basic employment and traveling time data by residential location for zip code level in Summary File 3 for Census 2000.

1.b Calculate the distance matrix between the zip codes. Internal distance is calculated as half of the radius by the area, treating every zip code as a round area.

1.c Calculate f and a parameter by using the sum value for the whole region.

$f = P/E$, dependent ratio

$a = Es/P$, service employment demand ratio

1.d Calculate housing capacity Hi, and service capacity Sj

According to the common knowledge of land use, the larger is the area, the higher is the capacity, assuming the urban landscape is homogeneous. The density is critical for the capacity calculation. I take the average of maximum density and mean density as the capacity density for both population and service employment for simplification.

Step 2: Allocate employment by gravity model

2.a Calculate housing capacity weight by gravity model

$Wi = Hi/Dij$ --7.7

i housing zip code

j employment zip code

Hi capacity of housing in i

Dij distance between i and j

Ej employment working in j

Eij the number of employment working in j and living in i

The higher is the capacity, the larger is the weight. The longer is the distance, the less is the weight.

2.b Allocate housing for employment by housing capacity weight

$Eij = Ej*Wi/ \sum iWi$ ---7.8

$\sum jEij = Ei$, all employment living in i,

$\sum iEij = Ej$, all employment working in j, Step 3: Allocate population and service employment by gravity model

3.a Calculate population by the Ei

$P_i = f*E_i$, total population in i

A check is performed to see if a unit is allocated more population than its capacity. The excess population indicator is:

$IH_i = H_i/P_i$, ---7.9

If IH_i is less than 1, then i is overpopulated, and H_i will be corrected, P_i-H_i will be relocated into the neighborhood units (adjacent polygons) by the new weights.

3.b Calculate service employment demand in i by Pi

$E_{si} = a*P_i$ ---7.10

3.c Calculate service employment capacity weight by gravity model.

S_j capacity of service employment in j

W_j: service employment capacity weight for j:

$W_j = S_j/D_{ij}^2$, ---7.11

the higher is the capacity, the larger is the weight. The longer is the distance, the less is the weight.

3.d Allocate service employment by service employment capacity

E_{sij} the number of service employment located in j and serving for i.

$E_{sij} = E_{si}*W_j/ \sum_j W_j$ --7.12

$\sum_i E_{sij} = E_{sj}$, all service employment living in j,

A monitoring indicator is calculated to check if the unit is over populated with service employment than its capacity. The over population indicator for service employment:

$IS_j = S_j/ES_j$, ---7.13

If ISj is less than 1, then j is overpopulated, and Sj will be corrected, Esj-Sj will be relocated into the neighborhood units by the new weights.

3.e Calculate the total employment working in j

Ej2 = Ej1 + Esj ---7.14

Ej2 round 2 employment working in j; Ej1 round 1 employment working in j

Step 4: Recursive calculation to find final allocation

Normally Ebj is used as Ej1 in the first round calculation. After the first round, the Ej2 is used to substitute Ej1 for the second round calculation, and so on. The calculation and reiteration can be done by spread sheet in Microsoft Excel. The total population will be closer to the real total population for each calculation round. The total population after 9 rounds should be less than but approximately equals to the real total population.

Distance Decay Powers

There is a difference between the gravity model for housing and service employment. While one power distance is used to allocate housing, squared distance is used for service employment, which has a steeper slope. In Alonso's general equilibrium model, commercial activity's bid-rent curve is steeper, and always locates in the CBD area, while the housing bid-rent curve is flatter and always locates in the outer rings. By assuming different distance decay rates, the Lowry model agree with the results of Alonso's theory, the housing activity will be spread to neighborhood study units, while the service will allocate in the local unit. If the basic employment is concentrated in

CBD, the Lowry model's population and employment allocation pattern will be similar to Alonso's concentric zones.

The distribution of basic employment is taken as given by Commercial Census 1997. Other than this, seven pairs of variables can be used to evaluate the Lowry Model's fitness to the real world population and economic activity pattern. They are service employment working, total employment working, basic employment residency, service employment residency, total employment residency, total population residency, and commuting time. All these variables can be derived from the Lowry model for each zip code. The real world distribution of service employment, and total employment can be obtained from the Economic Census 1997. Residency for basic, service, and total employment by zip code can be obtained from the Census 2000, and population and average commuting time as well. The result for Sacramento and Fresno at 5-digits zip code level area follows (Table 15).

Table 15 shows that the service activity allocation has very low R square, while employment residency and population allocation have high R square for both cities. The commuting pattern matches better in Sacramento than Fresno. For medium sized cities commuting patterns have more freedom and are harder to predict. For large cities like Sacramento, commuting cost is large enough to be taken into consideration, and thus the theory better matches field data.

The distance decay power is to the power of distance used in the gravity model to calculate the weight for housing or service employment allocation. If we set the goal to simulate the population pattern, different distance decay power can be used to find the highest R square of population fitness. For Fresno, the distance decay power for service allocation is fixed at 2, and the distance decay power for employment residency allocation is changed from original 1 to 0.3, 0.5, 0.7, and 1.5 respectively. Then the R square of population allocation is plotted on different distance decay power used. The results fit a quadratic curve well (Figure 22), with the R square peak at distance decay power equals 0.7. The highest R square can be obtained is 0.7869. If the distance decay power for employment allocation is fixed at 0.7, and change the distance decay power for service allocation, the R square decelerate increases with the increase of distance decay power. The R square increase fast when the decay power is less than 2, while the increase is very weak when the index is greater than 2 (Figure 23). With the increasing distance decay for service, almost all the service is allocated in the same zip code, the further increase of decay power is meaningless for the allocation of service activity, and thus we can just take the distance decay power for service activity as 2. The sensitivity of R square as to the distance decay power for service activity is negligible comparing with the sensitivity of employment residency allocation. The former can just change the R square by 0.1%, while the later can change the R square by 5%.

For the case of Sacramento, different distance decay powers for employment residency are applied by assuming the distance decay power for service activity is 2. They are 0.5, 0.8, 1.0, 1.1, 1.3, and 1.5. A similar quadratic curve as Fresno is formed, if the R square for population allocation is plotted on the distance decay powers for employment residency allocation(Figure 24). The curve peak at 1.1, which is very close to 1, the default index taken. The R square change along with the different distance decay power for service activity is not tried, for R square is not sensitive with it according to the case study of Fresno. It is acceptable to take 2 as default distance decay power for service activity.

Table 15. R Squares for the initial Lowry Model of Fresno and Sacramento

R-squares	Fresno	Sacramento
Service employment working	0.2169	0.2292
Total employment working	0.6590	0.8513
Basic employment residency	0.7325	0.4982
Service employment residency	0.7403	0.4634
Total employment residency	0.7371	0.5163
Population	0.7793	0.5136
Commuting time (km vs. minutes)	0.0911	0.3104

The highest R square can be obtained by studying the sensitivity of R square to the distance decay power. We can conclude that the distance decay power associating with the highest R square fit the Lowry Model the best. Actually the distance decay power illustrate a city's profile. Such as the distance decay power of employment residency for Sacramento (1.1) is higher than Fresno (0.7), it show that Sacramento's employment residency trends to concentrate on the same zip code, while Fresno shows the trend of relatively more scatter.

Figure 22. The Effects of Distance Decay Power for Employment Residency on Lowry Model for Fresno, when Decay Power for Service Is 2

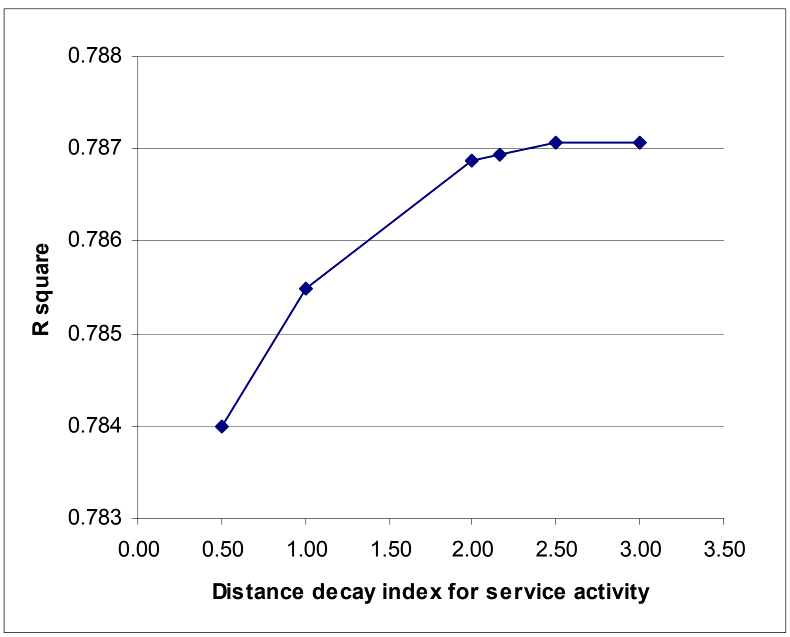


Figure 23. The Effects of Distance Decay Power for Service Activity on Lowry Model for Fresno, when Decay Power for Employment Is 0.7

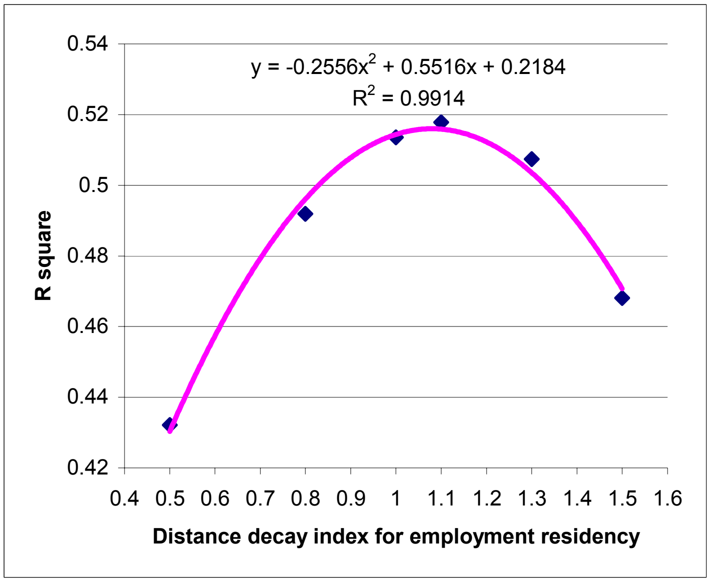
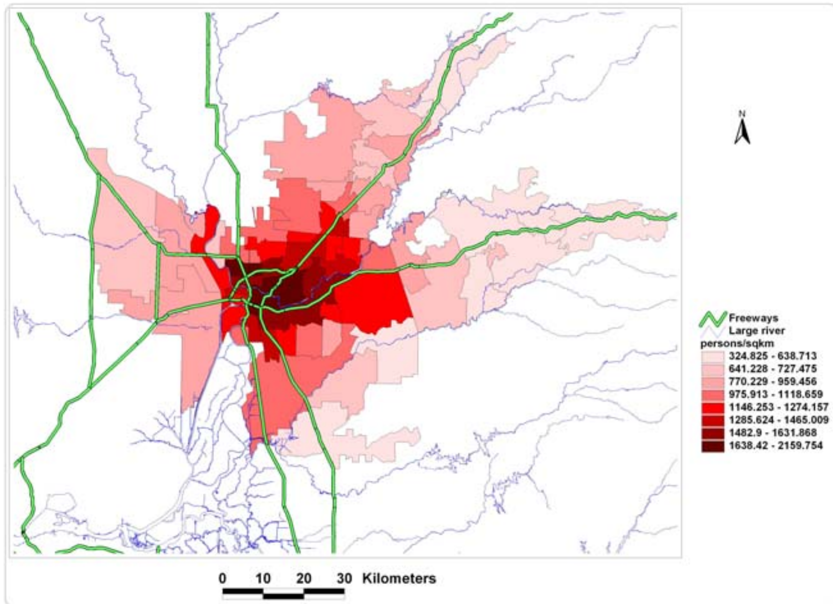
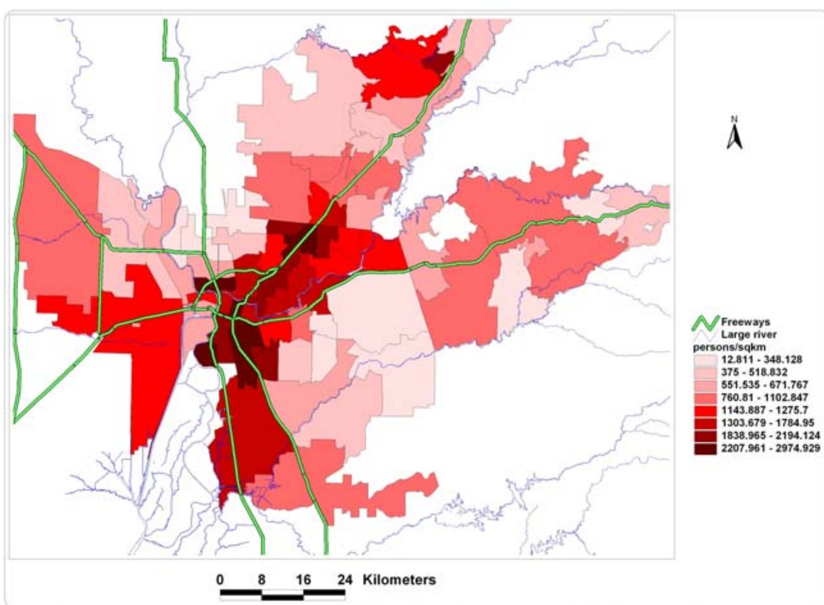


Figure 24. The Effects of Distance Decay Power for Employment Residency on Lowry Model for Sacramento, when Decay Power for Service Is 2

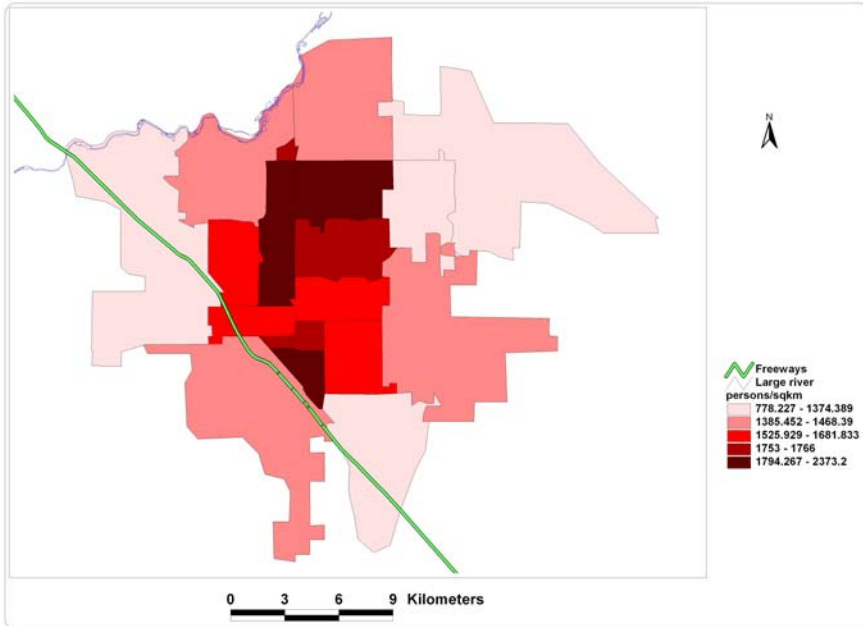
The Fitness of the Model

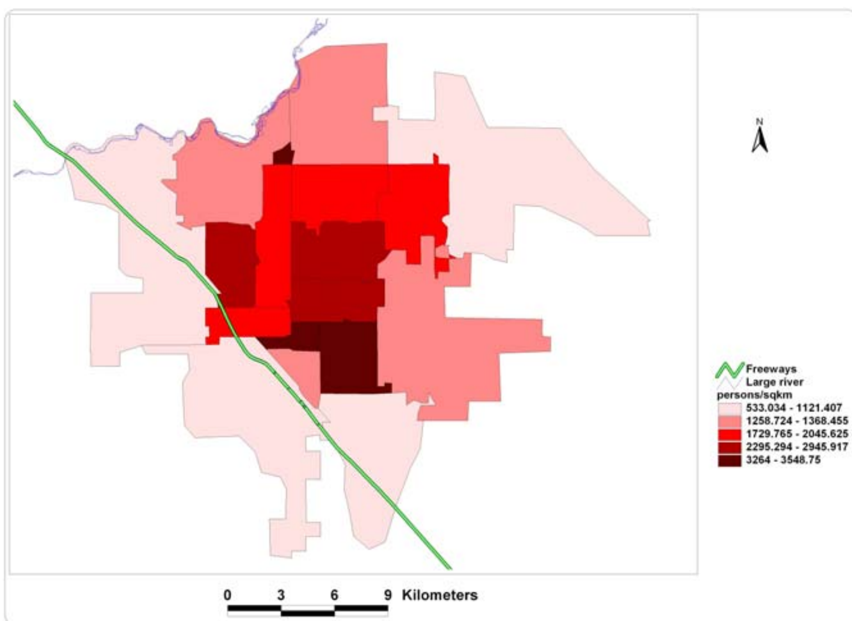
As shown in table 15, Sacramento have a relatively lower R squares for population allocation than Fresno. Generally, Fresno fit the Lowry model better than Sacramento. It can be explained by the fact that Fresno's landscape is more homogeneous than Sacramento's. A homogenous landscape is a basic assumption in Lowry Model. The complex physical settings for Sacramento affect the application of a gravity model in population allocation. Also, using distance instead of travel time makes Sacramento model inaccurate.



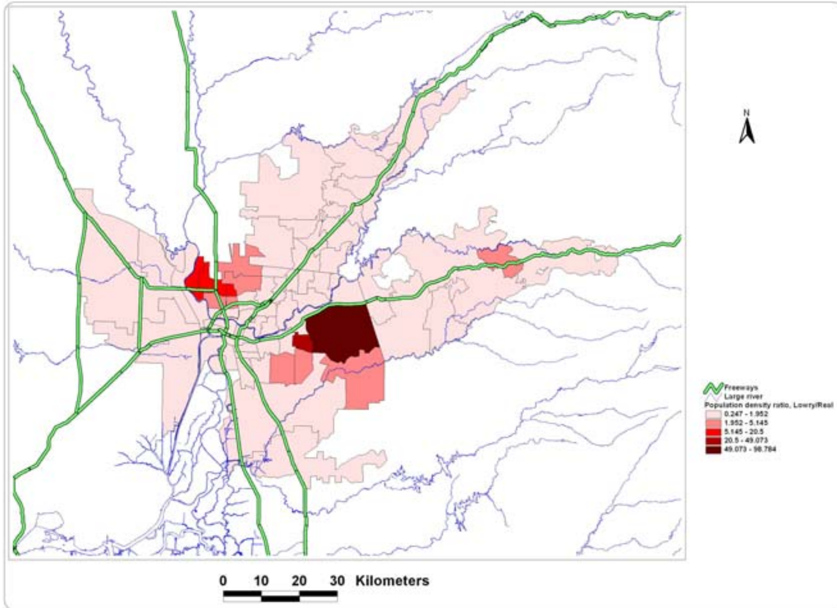


Map 9. Sacramento's Population Density: Lowry Model (Top) and Real (Bottom)

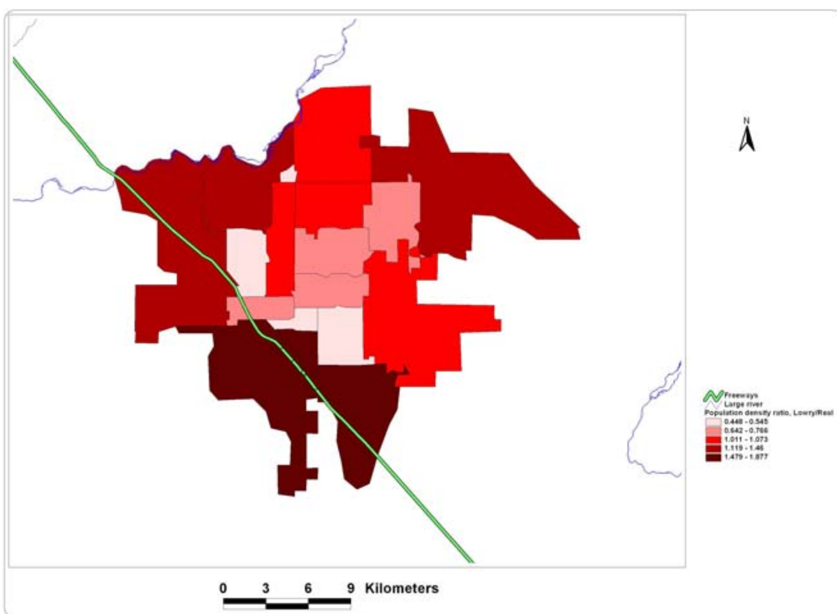




Map 10. Fresno's Population Density: Lowry Model (Top) and Real (Bottom)



Map 11. Relative Population Density by Lowry Model in Sacramento, Assuming Real World Population Density Equals 1



Map 12. Relative Population Density by Lowry Model in Fresno, Assuming Real World Population Density Equals 1

The significance of research on the fitness of real world pattern to the Lowry Model is to study the profile of internal urban structure, and probe for improvement in urban planning to build up an efficient urban structure in accord with the physical background of the urbanized areas. As shown in Map 9, the theoretical population distribution for Sacramento by Lowry model is more concentrated on the center of the city than the real world population distribution. Given that most land east of the Yolo Bypass is suitable for urban development, the Lowry model shows an efficient way to allocate urban population by minimizing transportation cost. Scattering to the east and north east, the real world population increased the transportation cost unnecessarily, and thus is inefficient. Measured by the population density ratio, Map 11 shows the difference between population density by Lowry Model and the real world population density. The theoretical density is much higher on the southeast and north part of Sacramento urbanized area. If more urban development occurs and more population moves in these two areas, the population distribution will become more efficient in terms of transportation cost. In the real world, it is impossible to relocate currently settled population to fit the model. Nevertheless, Lowry model's theoretical result can at least act as a goal for future urban development and planning.

Map 10 and Map 12 show the population distribution difference between Lowry model and the real world pattern in Fresno. The general trends for both of the population density are consistent with the concentric zone model. The high R square (0.779) for population density between Lowry model and real world pattern indicates the real world population density fit the Lowry model well. Ironically, the actual population distribution seems more concentrated on the center of the urbanized area than the Lowry Model's theoretical population pattern. In this case, improvement of population allocation for transportation cost saving purpose is to increase the population density in the fringe zip code areas, and in the mean time, to keep current high density area population stable. The overall result is to increase the overall population density for the whole urbanized area, and to create a more efficient compact urbanized area.

CHAPTER 8

LAND USE CONVERSION ANALYSIS

Land Value and Urban Growth Pattern

The marginal population density refers to the population density in the urban fringe. It is an important indicator for land use conversion forecasting. Pilot studies find that the higher values of the agricultural lands surrounding the city result in higher urban fringe population and housing cost densities. According to the household general equilibrium theory, land developers compete for profit with agricultural activity at the urban fringe. In an equilibrium situation for a free land market, the higher surrounding agricultural land values lead to higher marginal density in the urban fringe. The theoretical result matches the empirical finding (Figure 25). Landowners will hold land for agricultural use or a higher bidder unless the developer can pay the highest bids, whereas the high bids paid by the developer need to be supported by high population density and high housing cost density.

The urban fringe land values for 17 sampled cities in the central Valley were studied. As discussed in chapter 2, the land value at the urban fringe is composed of two parts, the agricultural land value and the expected future value of the developed land. The future land value generated by potential urban development is high in an urban fringe most likely to get development in the near future. The agricultural land value depends on the natural and economic productivity of the agricultural land. Given that all the 17 cities are located in the valley floor and agricultural technology extension is well done, the agricultural land value should be relatively homogeneous in the Central Valley area for each kind of land use category. However, the potential for future development varies among different cities. If we only use the agricultural land value to estimate the population density in the urban fringe, the population density will be underestimated. The developer can pay much more than the value for agricultural usage for a piece of land in the urban fringe to convert it into residential land use. Land value and rent data from California chapter of American Society of Farm Managers and Rural Appraisers (ASFMRA) in 2002 shows market land values, and thus it contains both the agricultural land value and the potential value for future development. Our goal is to study the relationship between population density and the land value in the urban fringe. The land price reflects the developer willingness to pay in the urban fringe. The labeled land value is consistent with the theoretical assumption, and thus it is suitable to be used as an independent variable for the marginal population density in the urban fringe for population density estimation purpose. In the case studies, it is better to decompose the labeled land value into agricultural value and future development potential value. It would be helpful for forecasting the urban density and determines the related countermeasures for land use management if the land price components are clear. The high percentage share of potential development land value of the total land value is a good indicator of the regions of land use conversion pressure by fast urbanization or high potential of development in the near future.

Redding is surrounded by native vegetation with low economic land value (Map 13). About two thirds of its urban fringe is rangeland, and one third is cropland. The urbanized area grows loosely, and the population density is very low. Redding’s urban fringe land value for both rangeland and cropland are lowest in the 17 sampled urbanized areas, and its total land value can be treated as pure agricultural land value, and they are a representative background land value for other urbanized areas.

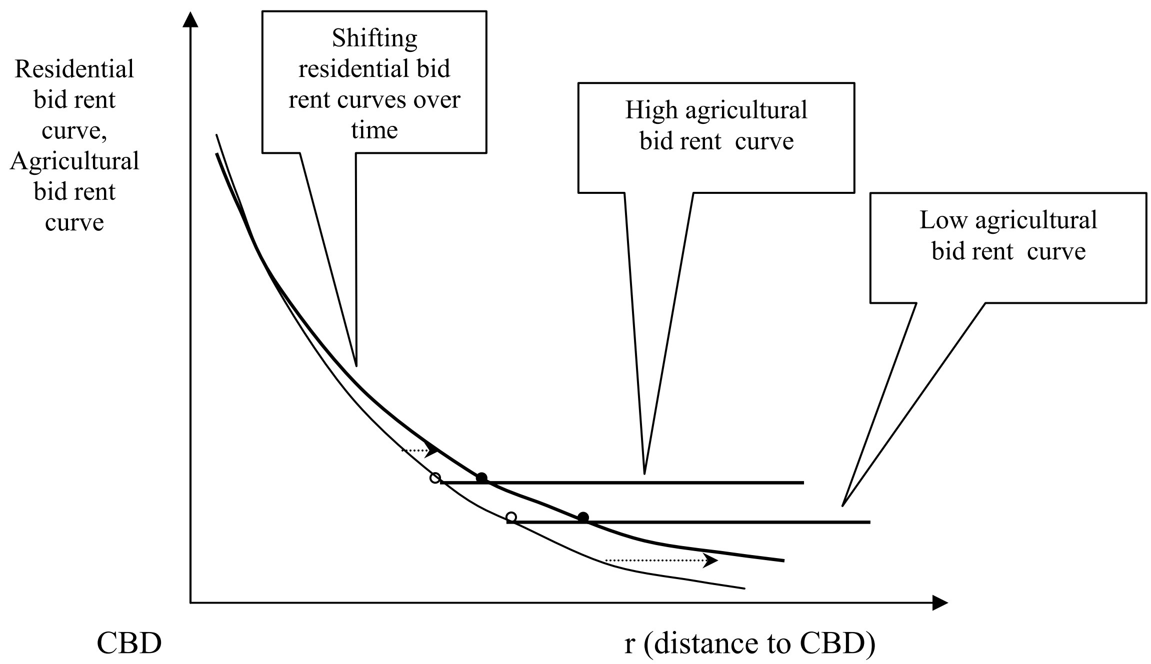


Figure 25. Household General Equilibrium in the Urban Fringe

Fresno is surrounded by vineyards, citrus and deciduous orchards in the west, north, and south. It is open to native vegetation on the east (Map 15). The unsymmetrical growth of the urban to the east can be called the squeeze-out effect. And it can be explained as the lower land value in the east is attractive for space loving consumer and rational land developer. Is it possible that the anticipated growth lead farmers to not invest in high value crops? Two arguments can rule out this “chicken or egg” problem. One is the rolling hills east of freeway 99 are less suitable for cropping by way of irrigation and application of agricultural machines than the flat land on the west side.

Another is that case of new investment on developing vineyard on the hot spot sighted in the field trip at northwest Sacramento. We can conclude that the farming activity is mainly determined by natural suitability, and anticipated urban growth has minor affect on the farming investment.

Galt is part of Lodi urbanized area according to the official definition by Census Bureau in 2000. Lodi is surrounded by high valued vineyard. The vineyard price is between $140,000 and $180,000 per acre, which is much higher than a background price in the Central Valley area for vineyard, $5,500 per acre. The high land price for vineyards can not just be explained as driven up by potential urban development. It is caused by the infrastructure and technology input in Lodi. High natural productivity may be another explanation of Lodi's high vineyard land value. The urbanized area is constrained to a compact shape by the high background agricultural land value, and the population density is higher than other cities with similar size. If the population density is calculated separately for Lodi and Galt, the population density for Lodi is 1628 persons per square km, while the population density for Galt is just 943 persons per square km. Galt is surrounded by cropland, which has much lower land price comparing with the vineyard surrounding Lodi. We can anticipate that Galt will be future bedroom community for people in Lodi who search for large space to live.

The land use pattern in the urban fringe of Sacramento is complex (Map 14). The flood bypass lies on the west, and it creates bridgehead effects for the growth of Davis and Woodland. It is open to native vegetation to the northeast, east, and southeast and south. Rangeland occupies half of its urban fringe, and there are few high valued vineyards and fruit orchards in its near suburb, so the background agricultural land value is not high for Sacramento. However, more than half of its total land value in the urban fringe is generated by high potential development.

To decompose the land value into agricultural land value and potential land value for future development, 17 sampled urbanized areas in the Central Valley were studied. First, the weighted average land value in the urban fringe is estimated for different land use categories for each of the 17 urbanized areas according to data for 2002 provided by ASFMRA. This is the total land value in the urban fringe of the sampled urbanized areas. The land value for potential future development is estimated by subtracting the minimum land value for each agricultural land category among the 17 urbanized areas, and then weighted average the agricultural land value according to the area share of each agricultural land use category, which is similar to the process to calculate the total land value. Table 16 shows the estimated result of the land values and their decomposition. The percentage share of potential development value is high for the urbanized areas around the Delta, they are Stockton, Woodland, and Vacaville. Antioch, and Sacramento. The urbanized areas in the north of the Central Valley (Redding, Yuba City, and Chico) and the small urbanized areas in the southern part of the Central Valley, such as Delano, have very low potential development value share (Map 16). The potential land value share patterns are consistent with the aggregate gravity pattern.

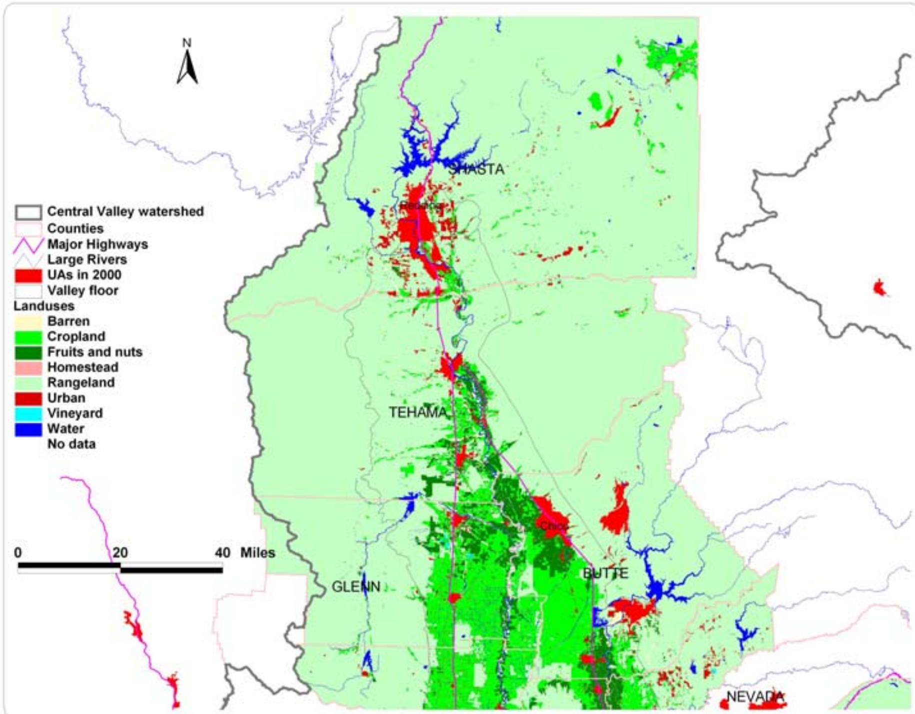
The Empirical Model for Marginal Population Density

The definition of urbanized area has changed dramatically in the 2000 census comparing to the 1990 census. In the 1990 Census, the Urbanized Area (UA) comprises one or more places ("central place") and the adjacent densely settled surrounding territory ("urban fringe") that together have a minimum of 50,000 persons. The urban fringe generally consists of contiguous territory having a density of at least 1,000 persons per square mile. According to these criteria, only 14 cities in the Central Valley watershed were categorized as urbanized areas. With a total population of 52,592, Davis is the smallest one. For the Census 2000, the Census Bureau classifies "urban" as all territory, population, and housing units located within an urbanized area (UA) or an urban cluster (UC). It delineates UA and UC boundaries to encompass densely settled territory, which consists of core census block groups or blocks that have a population density of at least 1,000 people per square mile, and surrounding census blocks that have an overall density of at least 500 people per square mile. In addition, under certain conditions, less densely settled territory may be part of each UA or UC. According to Census 2000 data, there are 113 urbanized areas located in the Central Valley watershed; 110 of these are totally located in the study area, including 6 prisons and public communities like Central California Women's Facility. This leaves 104 observations to model the relationship between marginal population density and the surrounding agricultural land value. The marginal population density is estimated for the 17 sampled urbanized areas by their population density function derived in Chapter 5. The average population density is used as marginal population density for other urbanized areas. The land value is estimated according to the average land value surrounding the city.

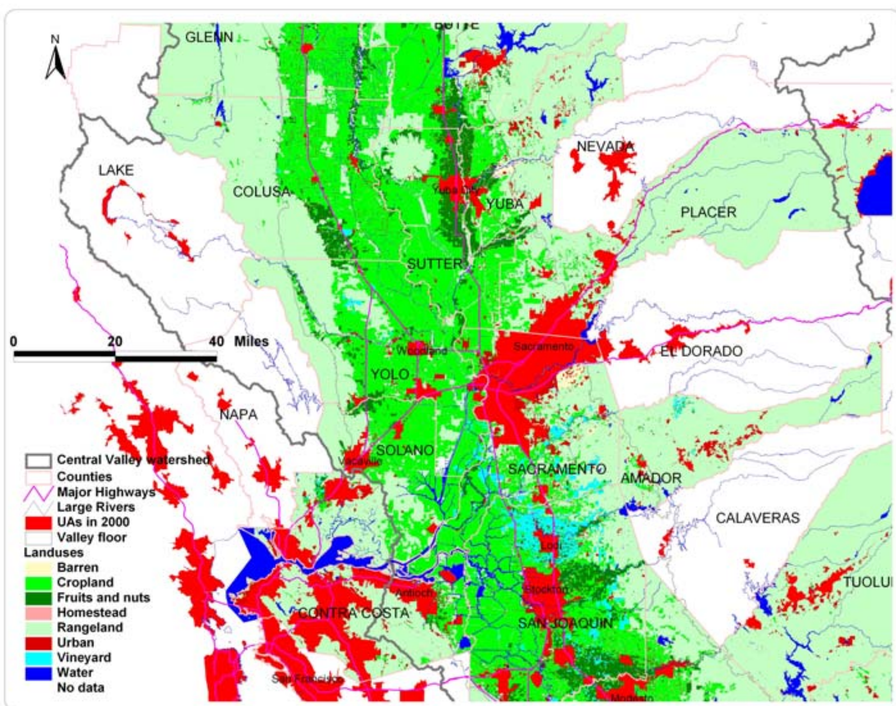
We can test the result of the household general equilibrium theory by running regression between the marginal population density and the land value. If the regression results in a positive relationship with high R square, the theory is confirmed. Otherwise, if the regression shows random relationship with low R square, the theory can not be accepted. According to the data available, 104 urbanized areas in the Central Valley are used for regression. The result shows power linear relationship with R square equals 0.5476 (Figure 26), which confirms that the theory is basically acceptable.

Table 16. Urban Fringe Land Value Decomposition for Central Valley Cities in 2002

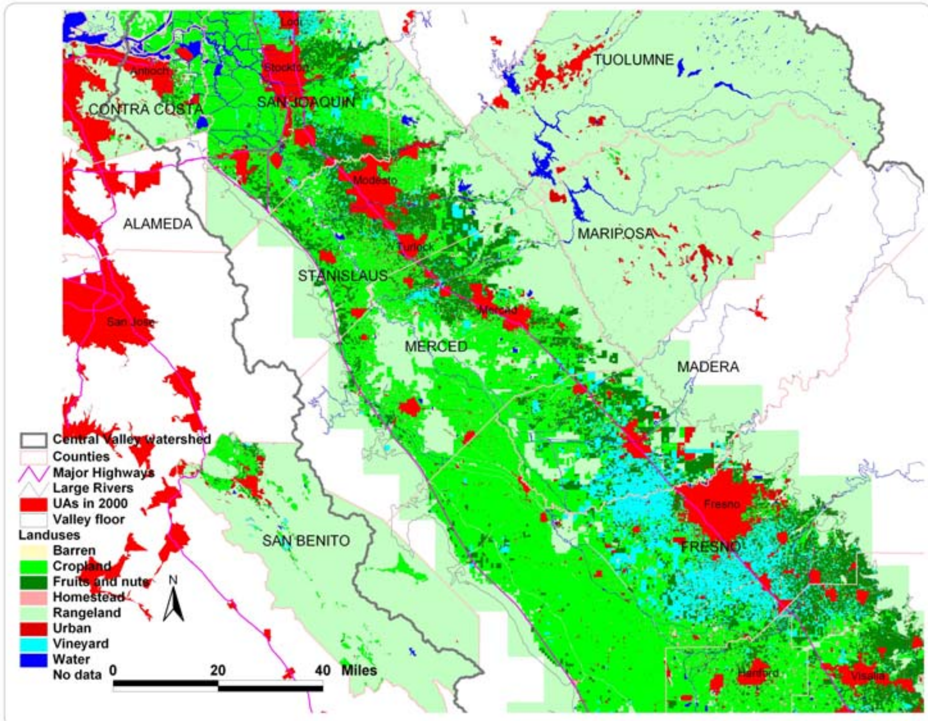
UA	Population of UA	Total land value $/acre	Land value for potential development, $/acre	Percentage share of the potential value, %
Redding	105267	816	0	0
Delano	39512	5525	365	7
Yuba City	97645	4870	390	8
Chico	89221	2878	405	14
Bakersfield	268800	2850	410	14
Fresno	554923	4150	745	18
Hanford	69639	3248	638	20
Merced	110483	2815	628	22
Visalia	120044	4600	1140	25
Modesto	310945	4800	1340	28
Turlock	69507	4950	1830	37
Stockton	313392	4600	2160	47
Woodland	49168	4000	1900	48
Vacaville	90264	2720	1410	52
Antioch	139453	4350	2305	53
Sacramento	1393498	2400	1288	54
Lodi	83735	9975	6005	60



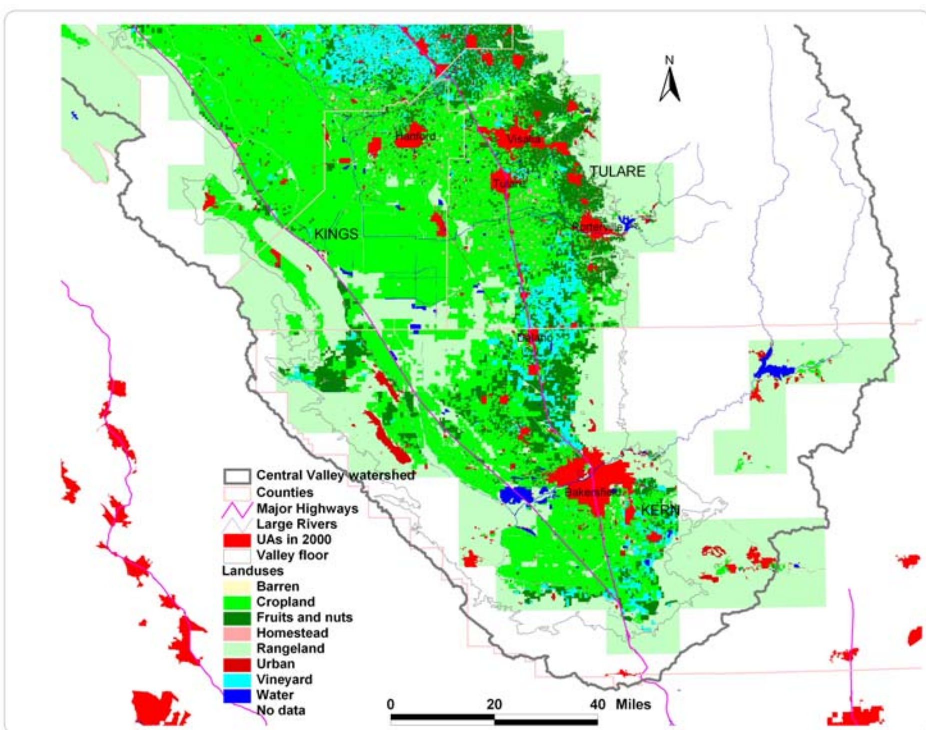
Map 13. Land Use Patterns in Northern Central Valley



Map 14. Land Use Patterns in the Delta Area



Map 15. Land Use Patterns from Stockton to Fresno



Map 16. Land Use Patterns in Southern Central Valley

Another interesting finding from the figure is that the variance of the marginal population density tends to be larger with the increase of land value. The theory fits the empirical result poorly for the high land value samples. The high land values are always associate with the fruit and vineyard crops, in which the agricultural infrastructure input share is a large portion of the land value. Both of these land values are not consistent with the basic assumption of the concentric zone model, which states that the land value is supported by the pure agricultural productivity or the net profit made by a real estate dealer.

Marginal population density is the result of real estate developer's behavior, and is consistent with local construction style. The local construction style determines the average population density, the marginal population density is the combined result of land value and the average population density for the urbanized area. The 17 sampled urbanized areas are taken as cases to be studied. The marginal population density is regressed on two independent variables, the average population density and the background land value in the urban fringe. The result has a power function, and have R square as high as 0.876 (Table 17).

$$MD = 0.02077 * AD^{0.70741} * LV^{0.70013} \quad \text{-----------------------} 8.1$$

MD: marginal population density

AD: average population density

LV: background land value in the urban fringe

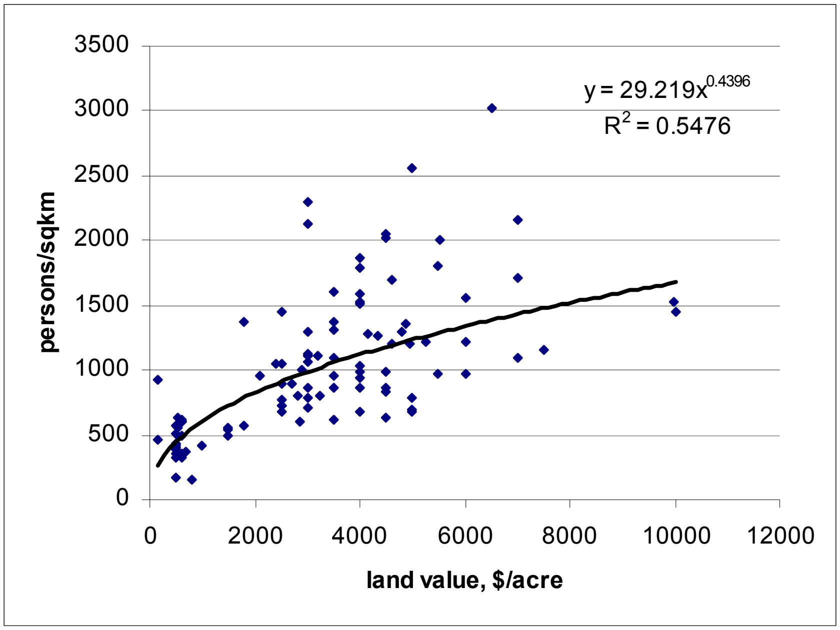


Figure 26. The Relationship between Land Value and Marginal Population Density for 104 Urbanized Areas in Central Valley in 2000

Table 17. Regression Result of Marginal Population Density model

lnMD	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	-3.87421	1.185312	-3.26852	0.005602
lnAD	0.70741	0.213167	3.318567	0.005071
lnLV	0.700125	0.137858	5.078603	0.000168
R Square	0.87600	Observations	17	

The theory also implies that the low value of land surrounding the urbanized area tends to be converted into the urbanized area first, if other location factors are the same. Evidence can be found through case studies. Redding and Red Bluff are mainly surrounded by low value rangeland, while some higher value cropland exists in its urban fringe. The urban growth between 1975 and 1998 in these two urbanized areas took mostly rangeland, while the cropland taken by urban growth is very limit unless the land is on the good location. Eastward unsymmetrical urban growth in Chico, Sacramento, Merced and Fresno also provide support that the low value land develops first argument. Detail urban growth analysis will be conducted in Chapter 10.

Social Factors and Urban Growth

Social factors such as local people's specific behavior and change of local population's social structure also affect urban growth. They are not studied in detail at this dissertation, but worth to mention and pay attention on.

Parcel data shows that small parcels with 5-40 acres locate all around most cities in the Central Valley. These are currently in agriculture, but are becoming hobby farms and commuter large-lot residences. DWR land use data shows these parcels as scattered homesteads surrounded by farmland. The homestead density is very high, especially on urban fringes and southern part of Central Valley. The Census population data by block for 1990 and 2000 show a lot of population growth in these large-lot areas out on the supposedly agriculture lands. These data, taken together, seem to show that most of the agriculture near the cities will become hobby farms and not commercial farms. We concern about land use conversion, the hobby farming is still categorized as agricultural land use. But the growth of homestead acreage should be monitored and counted as urban expansion, for the landlord have right to build on their land, and urban zoning regulation does not apply to them.

Household income trends are also factors affecting urban growth. Globalization and immigration in California mean a high percent of poor households. The incomes of the bottom 20-50% are falling in real dollar. A small percent of rich households have rapidly rising incomes. More apartments near transit are needed to accommodate the increasing poor population. And on the other hand the market demand for a few large rural estates in most counties will increase to satisfy the rich. The second home is the privilege of the rich, the increase of rich population and rich people's income may increase the demand for second home. The distribution of second home and consumer's behavior on second home selection is an interesting topic to study. The future income trend is critical to determine strategy for urban planning and evolution of future urban density. More poor people means urban planning need concentrate on downtown infill to increase population density, more rich people means urban planning need concern more about the suburbanization process and decreasing in average population density. The overall population density trend depends on the social structure evolution.

Demographics data of age for household heads indicates that there will be a great increase in households over 65 years of age. Being retired, they will be footloose and so can locate in the rural area, if they want. Trends seem to show upper middle income households going to active adult communities, like Sun City Roseville, while most retired households go to rural low cost areas in the Sierra foothills and elsewhere or stay in apartments and condos in cities. Amenity factor such as lake view and forest environment may also play an important rule in the housing allocation of the aged peoples. The house behavior for these aged peoples need to be studied in urban planning. For their percentage share among the total population is increasing, their housing behavior will have more affects on the housing market.

CHAPTER 9

FORECASTING FUTURE URBAN GROWTH

Theoretical Base and Current Land Use Forecasts for Central Valley

The theoretical framework to explain land use conversion started at Von Thunen's Isolated State (1826). The development of railroads and highways have expanded the concentric zone nation wide and even worldwide. Currently in the USA, most agricultural bidding curves can be treated as flat. Agricultural rent is determined mainly by the soil quality and the productivity of the crops. Similar to the Von Thunen's agricultural concentric zones, the household general equilibrium theory generates the concentric zone model of urban structure. Retailing has the steepest bid rent curve, for it is the most sensitive to accessibility considerations. The rent-biding curve for the industrial sector is flatter and thus it locates further from downtown. Following are high-density residential, medium density residential and low density residential, located further and further from the CBD. Competition for land through rent bidding between low-density residential and different agricultural activities in the urban fringe determine the land use conversion progress, modified somewhat by land us regulations.

Dynamically, when the population is growing, or the people's income grows and drives more people move to suburbs, residential land is scarce and thus its bid rent curve shifts up in the urban fringe. The equilibrium point migrates further from the CBD, the urbanized area is enlarged. Another universal case of urban expansion is the residential bid rent curve becomes flatter over time, caused by improved transportation technology.

Given that agricultural bid rent curves did not change significantly over time, it can also generate the outward migration of the urban fringe over time. Critically, in the past decades, the transportation development makes the retail, industrial and residential curves flatter and flatter. The random population density and housing cost density of the 6 sampled cities shown in chapter 5 is an extreme example of this trend. Actually this makes it easier to forecast land use conversion. All we need for these cities are forecasts of their population growth, and then just calculate the land use conversion according to the average population density. The location of the new urban growth is determined by transportation and the physical terrain.

Kuminoff, Sokolow, and Summer have done empirical study on land use conversion in the urban fringe of the central valley area. They modeled land use conversion at the county level through multivariable regression on 7 factors: changes in farmland income, changes in the price of agricultural land for development, population growth, the stock of agricultural land in each county, zoning and development restrictions, and time period (dummy). The critical finding through their research is that urban factors, not farm income, have been the main cause of farmland conversion and new urban development in California (Kuminoff and Summer, 2001). The result is consistent with the theoretical model. Change in the farmland rent-bidding curve is trivial compared to the change of residential bid rent curve, and thus the urban factor dominates urban expansion, not the agricultural factor.

Landis, J. D. and Reilly, M (2003) conducted another empirical study. Their dependent variable is the change in development status between 1988 and 1998 of all potentially developable sites, measured on 1 ha grid cells. Four types of measures were included as independent variables: 1. Demand variables: the number of jobs within 90 minutes of a given grid cell, and the ratio of community median household income to county median household income. 2. Own-site variables: the squared distance from each site to the nearest freeway, a dummy variable that indicates whether the FMMP classifies the site as prime farmland, the average percentage slope of each site, a dummy variable indicating whether the site falls within 100-year flood zone. 3. Adjacency and neighborhood variables: the average slope of the cells within 1 km and within the 2 to 3 km ring of each subject site; the share of sites within 1 km and within the 2 to 3km ring of the subject site that are located in the 100-year flood zone; 4. Regulatory and administrative variables: the dummy variable whether or not a site is located within an incorporated city. To better account for systematic regional variations, they tested separate models for southern California, northern California, the Sacramento region, and the southern San Joaquin Valley.

Five assumptions applied in their forecast are 1. The same factors that shaped land development patterns in the recent past will continue to do so in the future, and in the same ways. 2. Jobs will continue decentralizing within California's four major urban regions — southern California, the greater San Francisco Bay area, the Sacramento region, and the southern San Joaquin Valley. 3. California's population will continue to grow, and at more or less the same rate and in the same spatial pattern as projected by the California DOF. 4. Average infill rates and population densities will increase with additional development. 5. With respect to the baseline scenario, no new freeways, or intra-and inter-regional rapid transit systems will be developed. Freeway road travel speeds will remain at current levels. The fifth assumption has transportation technology progress stagnant and fixed for 100 years.

The Gross Marginal Density Method

Population forecasts are available by California Department of Finance (DOF). The data covered 1970 to 2040 at the county level. I studied the period between 1975 and 2050 for 22 counties in the Central Valley area. The GIS data for urban land use expansion of the 22 counties studied is available from USGS, DWR and FMMP. The 22 counties studied covered all of the valley floor and most of the Central Valley watershed.

My method for land use conversion forecast can be called the Gross Marginal Density Method. It forecasts the urban land area by historical marginal population density and future population growth. According to the data availability, the method can be considered to forecast Central Valley's urban land use expansion at the county level.

Basic assumptions for the Gross Marginal Density (GMD) Method are that the land use conversion from rural to urban is only driven by population growth, and the land use conversion pattern (infill and new growth) stays unchanged over time. Followed is an illustrative example for GMD Method.

In 1990: the county has population 20000 persons and urban area 10 square km

$P1990 = 20000$, $A1990 = 10$

In 2000: the county has population 27000 persons and urban area 15 square km

$P2000 = 27000$, $A2000 = 15$

The change in gross marginal density between 1990 and 2000 can be calculated as:

$$GMD1990\_2000 = (P2000-P1990)/(A2000-A1990)$$

$$=1200\ persons/sqkm \text{ ------------------------------- } 9.1$$

In this case, population growth is a black box. We do not know how many people infill in the urbanized area, and how many people are moved into the new buildup area between 1990 and 2000 (Figure 27). For Central Valley's urbanization rate is high, the urban population percentage in a county is assumed to be stable, and most population growth will locate in the current urbanized area or on its urban fringe. All we know is that each square km of new urban area can support 1200 persons' county wide population growth.

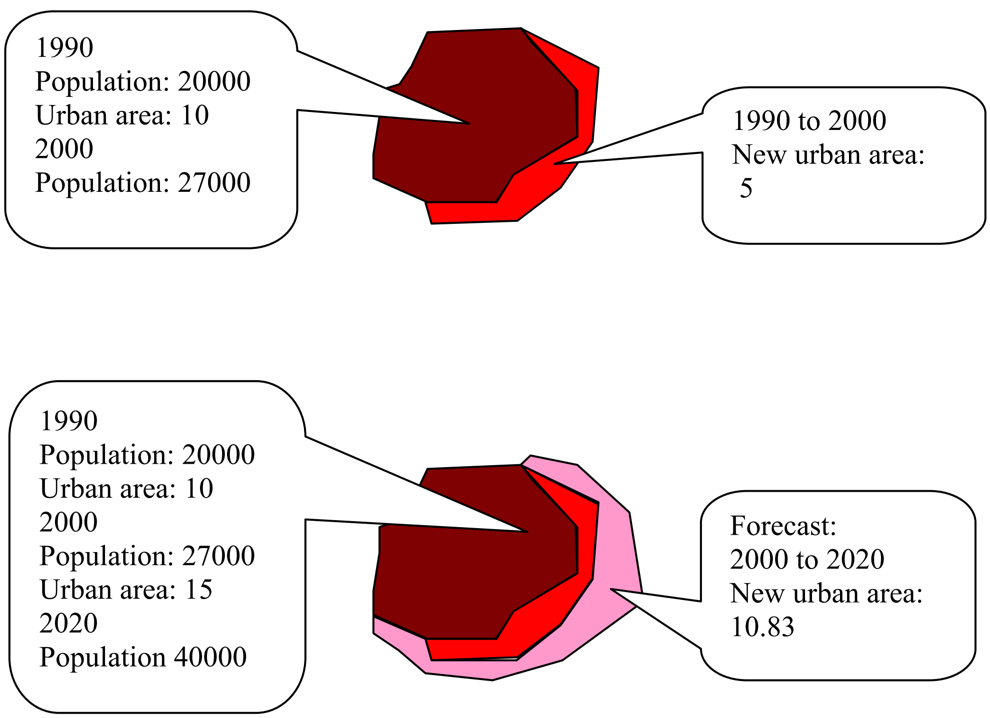


Figure 27. Schematic Chart for Land Use Conversion Dynamic Process

If, according the DOF of California, the county total population in 2020 will be 40000 persons, 13000 more than 2000, the question is how much land is needed to accommodate the population growth.

$$P2020 = 40000,\ \ A2020 - A2000 = ?$$

Assume infill and new growth between 2000 and 2020 will continue with the same pattern as in 1990 to 2000, we need 10.83 square km according to the following calculation.

$$A2020 - A2000 = (P2020 - P2000)/GMD1990\_2000$$

$$= 13000/1200$$

$$= 10.83 \text{ sqkm} \text{ -- } 9.2$$

Urban Land Use Forecast by Gross Marginal Density Method

Urban land use in 2020 and 2050 are forecast by using FMMP data in 1990 and 2000. The advantage of the data is that it is consistence in terms of data provider, and thus do not have problems of map projection match between two time periods. The whole area is mapped every two years and so very useful for detailed time series analysis. FMMP land use data concentrates on farmland protection. The minimum polygon for urban land use is 1 acre, approximately 60x60 square meters. The resolution is relatively low. Transportation land uses such as freeways and rail roads are not mapped. Rural farmsteads and subdivisions are not mapped for its low resolution. This data set can be used as a conservative estimate for future land use forecasts, because it tends to under estimate the growth of the urban area.

Urban land use in 2020 and 2050 are also forecasted by using USGS data in 1975 and DWR data in 2000. The resolution for USGS 1975 land use data is 20x20 meters, the resolution for DWR data is 10x10 meters. Both of data sets map transportation lines, but only DWR data have farmsteads mapped. This data set also has the disadvantage of map projection edge match. Different map projection systems do not match, in some cases the offset is 50-60 meters, the accuracy of forecast is undermined. But the land use category

Table 18a. Urban Area Estimation for 22 Counties by FMMP Data

NAME, sqkm	FMMP, 1990,	FMMP, 2000	FMMP, 2020f	FMMP, 2050f
Amador	26.1	29.8	34.0	37.8
Butte	145.9	162.6	232.1	347.6
Colusa	15.8	17.2	23.6	35.7
Contra C.	523.7	575.9	648.5	751.6
Fresno	329.4	392.6	531.7	812.9
Glenn	21.3	22.7	28.7	40.6
Kern	294.1	365.7	588.0	1056.6
Kings	103.9	117.1	149.4	213.8
Madera	80.2	93.4	128.2	193.9
Mariposa	8.6	9.0	10.3	11.8
Merced	86.5	127.9	251.3	504.2
Placer	119.3	167.7	271.8	410.2
Sacramento	556.1	636.0	850.7	1191.4
San Joaquin	258.1	300.1	433.4	674.9
Shasta	109.8	132.2	185.5	250.9
Solano	186.5	217.8	303.2	426.8
Stanislaus	181.9	223.9	349.0	567.4
Sutter	36.5	46.0	65.1	94.6
Tehama	39.7	46.4	73.1	116.5
Tulare	159.0	199.8	317.4	574.3
Yolo	90.8	105.0	143.6	213.5
Yuba	43.4	46.7	59.8	84.0
Sum	3416.8	4035.5	5678.4	8610.9

Table 18b. Urban Area Estimation for 22 Counties by USGS-DWR Data

NAME, sqkm	USGS, 1975	DWR, 1998	USGS_DWR, 2020f	USGS_DWR, 2050f	DWR 2020/1998
Amador	17.1	71.5	86.0	99.0	1.2040
Butte	137.3	184.9	240.0	331.8	1.2983
Colusa	31.6	56.7	119.3	239.8	2.1057
Contra C.	434.7	592.2	671.0	783.0	1.1330
Fresno	292.9	546.1	760.1	1192.6	1.3918
Glenn	32.7	45.7	71.4	122.0	1.5622
Kern	187.6	555.4	1017.3	1991.6	1.8318
Kings	44.1	98.2	154.9	267.7	1.5768
Madera	26.7	114.8	226.0	435.8	1.9693
Mariposa	19.8	90.3	146.4	212.6	1.6209
Merced	94.8	160.6	231.8	377.9	1.4439
Placer	115.9	197.5	276.5	381.5	1.4000
Sacramento	469.4	763.1	1010.8	1403.9	1.3245
San Joaquin	221.6	350.6	490.9	744.8	1.4001
Shasta	135.2	284.4	401.1	544.2	1.4101
Solano	136.6	215.5	272.3	354.3	1.2633
Stanislaus	232.9	250.4	269.1	301.6	1.0745
Sutter	30.7	58.6	85.4	126.7	1.4582
Tehama	49.4	68.0	89.2	123.6	1.3119
Tulare	158.3	258.6	375.0	629.7	1.4504
Yolo	85.5	123.2	160.3	227.5	1.3013
Yuba	49.4	94.6	144.2	235.2	1.5244
Sum	3004.3	5180.8	7299.2	11126.9	1.4089

of DWR data is listed in detail, and the irrigation status is also listed. It is suitable for water use forecasting. Compared to FMMP data, DWR's urban category is more detailed, and urbanized area is much larger than the FMMP data, for the lower density rural residential areas are categorized as urban area. Land use forecasts by using USGS and DWR data can be used as an aggressive forecast, which trends to over estimate the growth of urban areas.

The forecast results by applying the real world data for 22 Central Valley counties are shown in Table 18a and 18b. As shown in the table, DWR categorizes 28.8% more urban area in 1998 than FMMP in 2000, while both of the two forecasts expect about a 41% urban area increase from 2000 to 2020. The DWR-USGS forecast is ideal for an aggressive forecast for the 22 counties, while the FMMP forecast provides a conservative forecast.

Land Use Conversion Forecast by Detailed Categories

Data are also available for detailed categories of rural land which have been converted into urban land, but it is not suitable for forecasting long term future trends. The surrounding environment for urban growth is changing dramatically, the historical land use conversion pattern may not be repeated in the future. However, the historical land use change pattern is at least a profile of local land use conversion, and the trends are most likely to continue in the near future. And the forecast can at least be a reference for future land use plan, farmland protection, and open space preservation.

Detailed land use conversion patterns are studied by using DWR land use data in 1998 and USGS data in 1975. The study units taken are 22 counties in the Central Valley and valley floor area. 2676.4 square km of land were converted to urban area in the 22 counties between 1975 and 1998, three quarters of the land use conversion, 2010.8 square km, are happened in the valley floor. According to the land use conversion's physical environment, the 22 counties are grouped into three zones. Sutter, Yuba and other 3 counties in the north are the northern group. The central group has 10 counties, and it stretches from Yolo and Placer to Merced and Mariposa. The southern group is Madera and other 3 counties in the south. The four pie figures show the land use conversion patterns for the three zones and the valley floor (Figure 28, 29, 30, 31). More than half lands converted to urban uses between 1975 and 1998 in the southern central valley were cropland, flowed by range land and fruit land. Half is crop land in the central group, flowed by forest, range and fruit. Forest takes about 40% in the northern group, followed by crop land at 36%; other major categories are range land and fruit orchard. The valley floor's land use conversion is mainly from crop land (61%). The fruit orchard and range land share 14% and 13% of all land converted into urban respectively.

To estimate the land use conversion's detailed category in the future, the land use conversion profile for the three groups are used to estimate the land use conversion component in 2020 separately. The 22 counties studied will convert 2118.3 square km into urban uses by 2020. The aggregate of the result for the three groups shows that 1048.8 sqkm will be crop land, 248.8 will be fruit orchard. These two valuable agricultural lands take 61%. The other major categories are rangeland 368.5 (17%), and forest 285.7(13.5%). (Table 19)

The GMD method can forecast future land use conversion through simple calculations. The drawback of this method comes from its simplicity. Even through it can estimate the total land use conversion quantity, it could not decide where new growth is. To locate the new urban growth in the future, the detailed land use pattern needs to be studied for each city. For a large city like Sacramento, different directions have different net marginal densities, and need to be treated differently. And the farmland and rangeland ratio taken by new development may change over time due to physical geographic constraints. The future land use conversion ratio depends on the physical settings of the city.

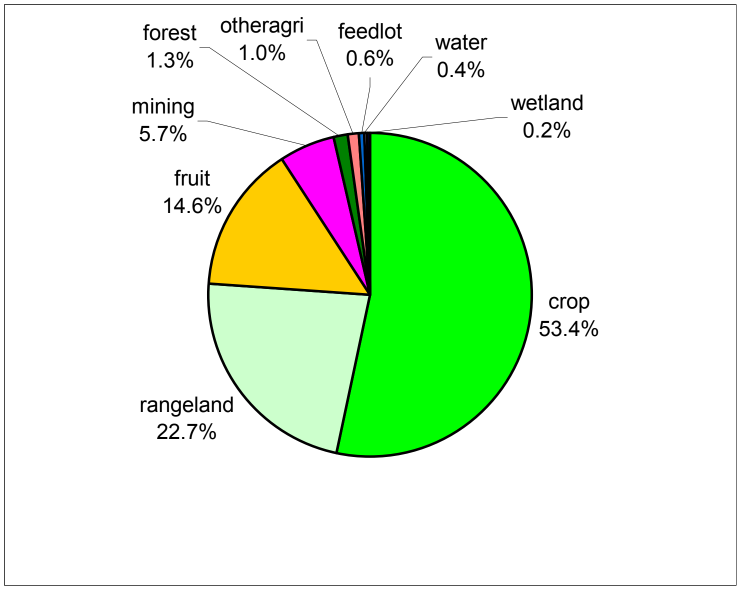


Figure 28. Lands Converted into Urban in Southern Central Valley, 1975-1998

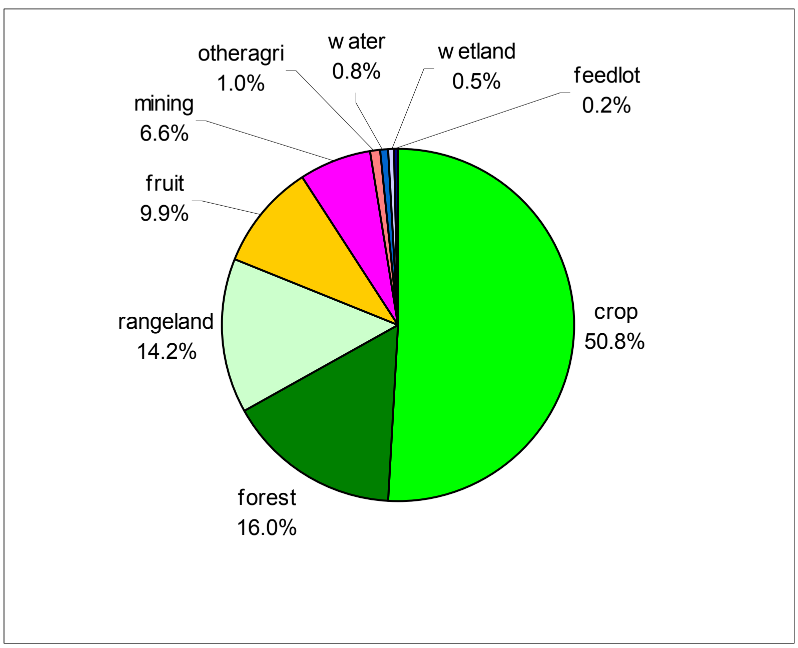


Figure 29. Lands Converted into Urban in Middle Central Valley, 1975-1998

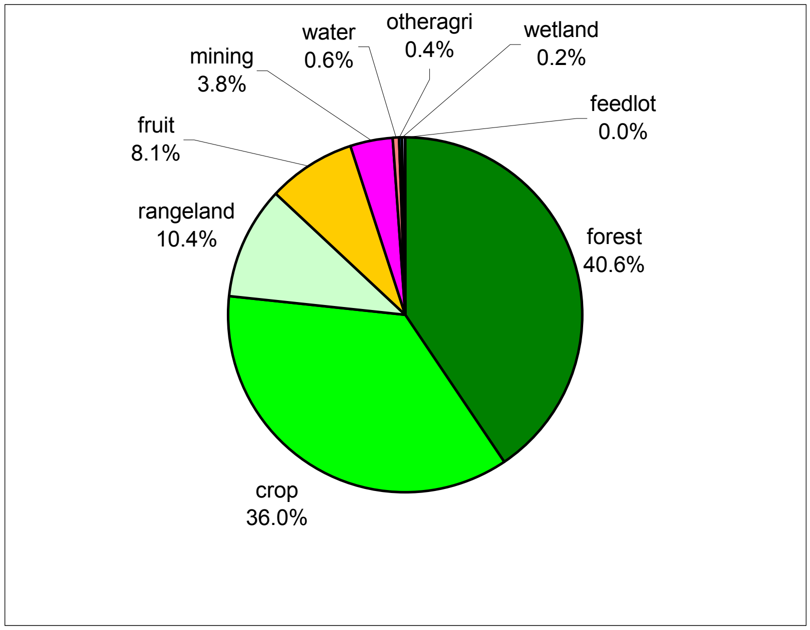


Figure 30. Lands Converted into Urban in Northern Central Valley, 1975-1998

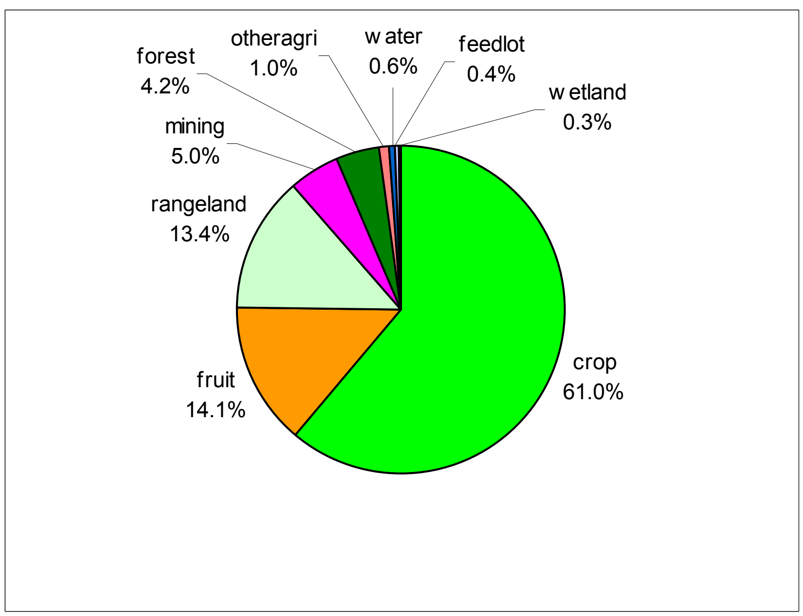


Figure 31. Lands Converted into Urban in the Valley Floor, 1975-1998

Table 19. Land Use Conversion Forecast for 22 Counties in 2020

Sqkm	Total	South	Middle	North
USGS, 1975	3004.27	681.49	1568.63	303.37
DWR, 1998	5180.80	1573.10	2814.90	792.80
USGS_DWR, 2020F	7299.20	2533.40	3615.20	1150.60
Urban Increase	2118.30	960.30	800.20	357.80
Crop	1048.81	513.28	406.79	128.74
Rangeland	368.47	217.85	113.52	37.10
Forest	285.70	12.68	127.92	145.10
Fruit	248.82	140.68	78.99	29.16
Mining	121.58	55.13	52.91	13.54
Other Agri.	18.21	9.25	7.70	1.26
Water	12.55	3.70	6.67	2.19
Feedlot	7.33	5.61	1.69	0.03
Wetland	6.82	2.12	4.01	0.69

Comparison of Different Forecasts

The GMD method is also compared with Landis's Logit model. Landis did not include northern central valley counties. Fifteen counties in the central and southern Central Valley are pulled from the 22 counties studied to compare with the forecast result of Landis's Logit model (Table 20, Figure 32). Comparison of my forecast with Landis's for the 15 counties in the Central Valley area shows that the sum of the 15 counties by FMMP data is very close to Landis's estimation, with 2.38% difference in 2000 and 8.21% difference in 2020. However, the differences for some counties are very large.

Table 20. Urbanized Land Area Forecasts for Central Valley's 15 Counties

Sqkm	DWR 1998	FMMP 2000	UCB 1998	DWR-USGS-GMD 2020	FMMP-GMD 2020	UCB 2020	FMMP/ UCB, 2020
Contra C.	592.2	575.9	555.5	671.0	648.5	602.5	1.0763
Fresno	546.1	392.6	377.7	760.1	531.7	488.9	1.0875
Kern	555.4	365.7	408.4	1017.3	588.0	651.2	0.9029
Kings	98.2	117.1	115.0	154.9	149.4	150.9	0.9900
Madera	114.8	93.4	90.3	226.0	128.2	153.5	0.8353
Merced	160.6	127.9	123.6	231.8	251.3	185.3	1.3561
Placer	197.5	167.7	152.8	276.5	271.8	237.8	1.1433
Sacram.	763.1	636.0	610.1	1010.8	850.7	719.5	1.1823
San J.	350.6	300.1	290.2	490.9	433.4	432.8	1.0014
Solano	215.5	217.8	214.7	272.3	303.2	278.2	1.0902
Stanisl.	250.4	223.9	204.3	269.1	349.0	251.4	1.3883
Sutter	58.6	46.0	43.1	85.4	65.1	63.9	1.0201
Tulare	258.6	199.8	197.0	375.0	317.4	301.8	1.0515
Yolo	123.2	105.0	103.7	160.3	143.6	129.2	1.1113
Yuba	94.6	46.7	45.3	144.2	59.8	58.2	1.0281
Sum15	4379.4	3615.6	3531.6	6145.6	5091.2	4705.1	1.0821

The difference between the FMMP-GMD result and Landis' estimation in 2000 and 2020 shows that different forecast methods will have different forecast results, even through the data employed is the same. It is hard to say which forecast is more accurate. If the numbers are very close for the county, the result should be closer to the fact. The forecast difference in 2020 is large, it is the result of methodology differences, and the accuracy of result can only be tested by real world progress. For Sacramento County, my forecast is much larger than Landis', for my forecast is conducted only by past trend, while Landis' forecast is based on more than 10 factors. The critical thing for the accuracy of forecast is that if the assumption of the forecast can hold in the future. The uncertainty of my forecast only depends on the continuity of one factor, while Landis's factor have more than 10 factors.

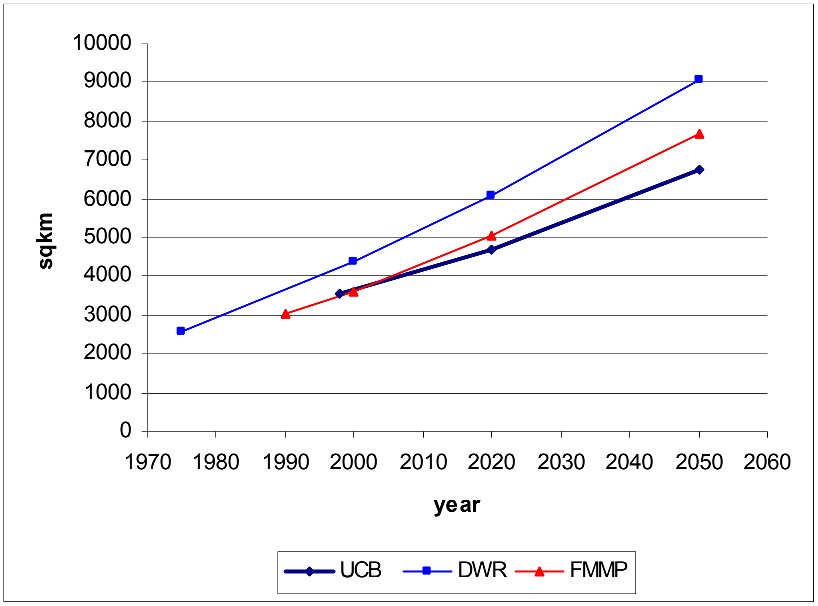


Figure 32. Forecasts for Urbanized Area for the 15 Counties in Central Valley

The other concern for the land use conversion forecasts is the trend of overall population density for the whole study area. The Logit model expects significant increase of overall population density, such as for the 15 counties studied the overall population density will increase from 1833 persons/sqkm in 1998 to 2095 persons/sqkm in 2050. The trend of overall population density by GMD method is increasing, while the increase rate is smaller than the Logit model. The overall population density for 15 counties by DWR-USGS data with GMD will increase from 1478 persons/sqkm in 1998 to 1556 persons/sqkm in 2050, while the population density will increase from 1790 persons/sqkm in 2000 to 1838 persons/sqkm in 2050 by FMMP data. We can not evaluate which expectation is better, the real world experience is the only effective way to test the model's fitness.

CHAPTER 10

IN SEARCH OF EFFICIENT URBAN GROWTH

Defining Efficient Urban Growth

Chapter 9 predicted the total land conversion to accommodate future urban growth. However, to forecast the detailed location of future urban growth is more difficult. Growth on the urban fringe is affected by a complex set of physical, economic, regulatory, and cultural factors, varying with situation and time. To find the way of efficient growth, we must consult economic theory. The Gross marginal Density (GMD) method only predicts the total amounts of future urbanization at a county level. It leaves room for a qualitative discussion of efficient patterns of urban growth. By applying economic theory, the efficient form of growth can be found. And the efficient form is critical advice for urban planners. The case study will be conducted for critical areas and typical cities: Sacramento, Fresno, the fringe of the Bay Area, Bakersfield, Redding, Modesto and Stockton. Both the comments on current urban development in these urbanized areas and the schematic designation for future urban growth are based on conceptual thinking by myself according to the neoclassic economic principles. The ideas of urban growth are speculative, and open to criticism from both urban developers and aggressive environmental conservationists.

The economic theories can be applied to suggest efficient urban growth. Based on cost minimization, Alonso's model maximized the utility for both poor and rich, and thus can suggest efficient growth patterns. Spill over and backwash effects are associated with

Alonso's theory. The spillover refers to decentralization of a high density urban core, mainly caused by richer people seeking for more living space and amenity environment in the suburbs. The process normally decreases urban population density, unless infill growth takes a significant portion of population growth. Even though population density may decline, spillover can be efficient, for people overall get more utility and satisfaction by moving to the suburb. The backwash effect refers to people moving into the urban area from a rural society; it is a consolidation process. The backwash effect normally dominates the population movement in the early age of the urbanization. In China, urbanization is now underway, and people are moving from rural society to towns and cities of different sizes. While strong in the early 20th century, the backwash effect is now weak in USA. However, some census tracts in the mountains surrounding Central Valley encountered weak population decline between 1990 and 2000, aftermath of backwash effect. The backwash effect increases population densities through a consolidation process and is efficient in terms of transportation cost saving and movement of people to more productive economic activities.

The Lowry model is an application of the concentric zone model, and thus has some theoretic basis for allocating population and service industry efficiently. Because the Lowry model allocates population given a current allocation of basic industry, it is widely used in urban planning. The shortcoming of the Lowry model is that it can not decide whether the allocation of basic industries is efficient or not.

The central place theory illustrates an efficient way to allocate cities and towns, and the structure of the urban system is efficient by different views, such as minimized transportation cost, minimizing marketing cost, and effective administration, or the combination of several perspectives. Central place theory determines an efficient urban structure and city allocation, which can make up for this shortcoming of the Lowry model.

Environmental protection can also result in efficient land use. If the environmental protectionist wants to preserve pieces of land from development, they can purchase the land and covert it into a nature preservation area or regulate its use by zoning. Environmental protectionists want to preserve land to satisfy their desire for environmental protection, or to retain the open space and environmental area as a luxury good for the public. Once the market scheme is introduced, use of a piece of land depends on who can pay more to have it for their purpose. The developer is seeking maximum profit, and when the house is sold, the consumer gets satisfaction by moving into a desired location. The housing market is driven by the market. By extending the market to the land market between real estate dealers and land preservationists, the land use result will be efficient, only if the developer can sell their houses out or the preserved land can attract substantial paying population to visit and satisfy the aesthetic desires of people.

The land market creates efficient urban growth under the assumption that urban growth does not generate externalities to third parties, or the externality is negligible compared with the benefits for urban growth. However, in real world cases, urban expansion generates negative and positive externalities to the third parties. In California, the smog problem is rooted in increased use of automobiles. Even though the smog problem can be reduced by auto smog tests, other externalities cannot be ignored. Congestion in highway and downtown parking, the noise pollution and air pollution generated by automobiles, and the water pollution and waste water disposed from the cities, are all externalities companying urban growth. The land use planner has responsibilities to reduce or eliminate these externalities through land use planning and regulation.

Vacant land in current urbanized areas is another source of inefficient urban growth. It may be the fault of urban planners, or land developers or the original land owner. If the land is vacant in the urbanized area for a long period, it wastes land resources, raising transportation costs and related externalities. If the land is surrounded by built up area, it can not be used for agriculture. It is hard to be used for urban purposes if the size and shape are not suitable for development. Environmental use of land also needs substantial land area, and vacant urban land is often too small for environmental uses.

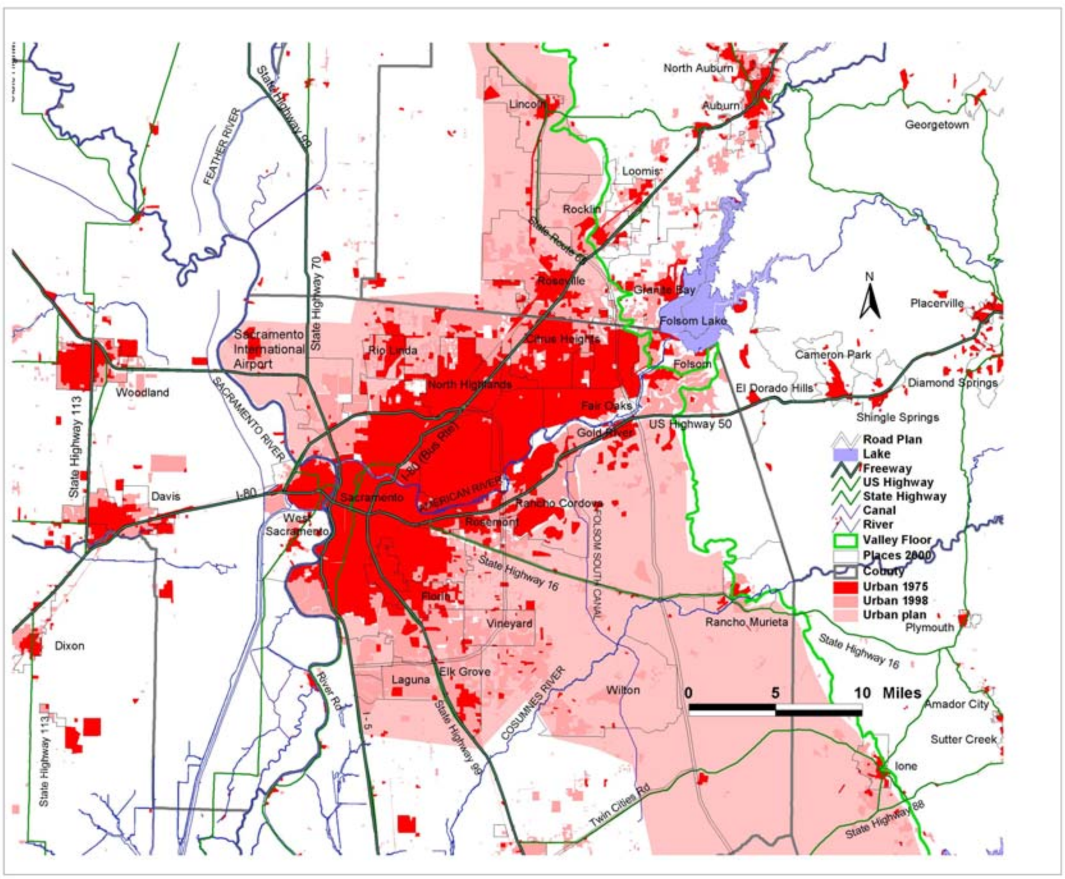
According to Alonso's model, the wealthier people prefer to live in lower density suburb communities. Leap frog development normally costs more in transportation, compared with continuous growth. Leap frog development has another disadvantage of pushing expansion of urbanized area, and it tends to create larger pieces of vacant land between old urbanized areas and newly urbanized areas. America is famous for mechanization in agriculture, Once the land is separated from the large piece, the land will not be cultivated, and will stay vacant until later urban development. Continuous urban development creates a more compact community and higher average population density.

The coordination among service, residential, and transportation land uses in land use planning are critical to create efficient urban growth. Proper land use planning should use economic models as a guide. Economic models, like Alonso's concentric zones in urban land use and the Lowery model's principle of minimizing transportation cost, are efficient by economic theory and can help guide land use planning.

Probing for Efficient Urban Growth in the Central Valley

I will try to find the efficient way of urban growth by applying economic theories and analyzing the sources for inefficient growth in the Central Valley area. We have the quantitative land use conversion forecast for each county already. If we can identify an efficient growth pattern for each city, it will be good economic guidance for Central valley's future urban growth. The GMD model can not predict the detail location of the future urban development, the analysis for efficient urban growth will make up for the disadvantage of the method for locating the future urban growth.

According to USGS's land use data, Sacramento's core area and eastward urban growth orientation were formed by 1975. Continuous growth dominates Sacramento's urban growth pattern since 1975, while the detailed patterns differ for different directions (Map 17). Most vigorous growth occurred in the south between Interstate highway 5 and Freeway 99 and east of freeway 99. A typical leap frog urban growth pattern exists east of freeway 99. The eastward urban growth mainly occurs along the interstate 80 and freeway 50. The new growth along interstate 80 concentrates on Citrus Heights to North Auburn to the east of valley floor. The urban growth in the valley floor part is spatially continuous while urban growth in the foot hills and low mountain areas is leap frog. Infill dominates new urban growth along freeway 50 in the valley floor. Land use data for the foothills and low mountains along freeway 50 is not available for recent years. According to the growth pattern in the foothills and low mountains along interstate 80, similar patterns of leap frog urban growth at this section are expected. Recent Landsat 7 images show new urban growth extended as far as Diamond Springs and Placerville, more than 40 km from the east edge of valley floor. Northward urban growth at North Highlands has extended the build up area to the northern border of Sacramento County. Leap frog growth in Rio Linda has left large areas of rangeland to its south. Large low density community exists between Rio Linda and North Highlands. Vigorous growth occurred on both sides of interstate 5 between the Garden Highway (on the American River levee) and Del Paso Road. Recent new urban growth extends to the northern side of Del Paso Road and the new construction frontier stretched to Elkhorn Boulevard.



Map 17. The Urban Growth on the Urban Fringe of Sacramento, 1975-1998

Even though it is threaten by flooding, there is still some continuous urban growth in West Sacramento in between the levees of Sacramento River and Yolo Bypass. But major westward urban growth is taken by the two bridgehead cities to the west, Davis and Woodland. According to the gravity model, Dixon belongs to Sacramento's influence sphere, and urban growth in Dixon is caused by spillover from Sacramento.

Although most of the landscape surrounding Sacramento is agricultural, land quality varies with location and land value differences are great among different land use categories. The cropland in the central part of valley floor is the most productive. Importantly, these lands are flat and continuous, and thus are suitable for running large agricultural machines, they are used either for truck or fruit crops. Lands on the edge of valley floor are less fertile agriculturally, and some are covered by rolling hills and thus are mostly not used for crops. When they are used for rangeland, the land value may drop from $4,000 per acre to $800 per acre. Moving east to the foot hills, rangeland domination increases, and croplands occur as small pieces scattered among rangeland. There are about 60 square km of abandoned mine tailings located east of Sunrise Boulevard and south of Freeway 50. Some of the mining ground is converted to urban usage. Lake Folsom is an amenity factor attracting lake oriented urban development. Substantial urban growth occurred on the south and west of the Lake since 1975.

The criteria for efficient urban growth can be summarized as close to current basic job location, close to freeway access, trying to avoid high value fertile farmland, locating the growth on flood free land, and more importantly, taking flat land as much as possible. According to the physical settings, Woodland, Davis, and Dixon's urban growth will mainly take high productivity farmland. The growth should be contained, and the growth pattern should be continuous and compact. West Sacramento is threatened by flood, and thus its urban growth should also be contained. Interstate 5 links downtown Sacramento and Sacramento International Airport. The lands on both sides are great locations for commercial and residential uses. Even though agricultural land productivity along this section of interstate 5 is high, it will be more efficient if the land is converted to urban uses. The area is also threatened by flood, while it is protected by Yolo Flood Bypass and the levee along east bank of Sacramento River. As Sacramento grows, and becomes an international metropolitan area, the international airport becomes more important as Sacramento's link with the outside world. The O'Hare Airport orienting urban growth in Chicago is a good example for Sacramento. The atmosphere of vigorous growth is obvious now in this area.

The section between Rio Linda and North Highland needs well planned infill growth. The growth on the north of Roseville is leap frog style, and infill growth is needed to form a compact shape. State route 65 has 6 km free way section linking interstate 80. The land along this section still belongs to the valley floor, and is currently used as rangeland. Vigorous urbanization is expected at this section. Seeking flat land for urban development may be the major reason for the leap frog development in the foothills. Infill and continuous development should be encouraged in the foot hills for efficient transportation utilities wild fire mitigation. Urban growth along interstate 80 to the east beyond Auburn should be limited, for the land turns to medium mountain and are covered by flammable pine forest. Costly fire protection measure, as well as high construction cost in mountainous terrain will make the urban growth there less efficient. Folsom lake oriented residential growth is expected to continue until the lake is surrounded by compact residential communities on the north, west and south. East of the lake is a peninsula and the road connection is not well established. The strategy for urban growth in El Dorado County should be similar to Placer County's mountainous section. Growth in foot hills and low mountain areas should be compact, and urban growth east beyond Placerville should be contained.

Sacramento's southward urban growth in the past decades left large areas of vacant land and fallowed farmland between the urbanized areas, and thus the infill development should be encouraged in this section. The fast southward growth is caused by the advantage of two parallel freeways (I-5 and route 99) running to the south, but further southward growth is losing this advantage for the distance to the CBD is increasing and the farmland taken is productive. Further southward growth is also blocked by the Consumes River.

Lacking of freeway access, Sacramento's southeastward urban growth is slow. Most of this sector is dominated by rangeland and rolling hills (Figure 33). It is suitable for urban development in terms of flat land, low agricultural productivity, and proximity to the CBD. Route E2 running parallel with the Consumes River can be used as a limit for Sacramento's southeastward urban growth. The area west of the south Folsom canal and north of route E2 (Grand Line Road) covered about 120 square km, in which about 20 square km is currently urban, and thus 100 square km available for future urban development. If the development is properly planned, and the new development can reach the population density of 3000 persons per square km, this section can accommodate 300,000 people, which can be a goal of urban expansion for year 2050. Further urban growth to the east of the canal is also possible. Proper water facility planned can support the conversion of another 100 square km into urban area. For the area is mostly not irrigated now, there is no water available to shift its usage from agricultural to urban, future urban development will increase water demand substantially. According to the urban water demand investigation by DWR (1998), the water demand for one acre of urbanized area is roughly equivalent to the water demand for one acre of irrigated cropland. Another critical issue is industrial location and transportation planning. Lowry model recommends residential locations close to industrial locations with transportation cost minimized. If we have large areas of land suitable for urban development, not only the transportation facility are needed to be improved to tighten the linkage with the CBD, new industrial park needs to be located at this sector in the land use plan for the Greater Sacramento area.

Figure 33. Rangeland Rolling Hill on the Urban Fringe of Southeast Sacramento

Spillover effects from Bay Area dominate the urbanization process in the west part of the middle section of the Central Valley in recent decades. Three routes link the Bay Area and the Central Valley, Interstate 80 on the north, freeway Route 4 in the middle and Interstate 580 on the south. Vacaville, Antioch and Tracy are three urbanized areas formed by spillover effects. Two more urbanized areas beyond Antioch are in their embryonic form, Oakley and Brentwood.

The physical background of the middle Central Valley differs sharply from the Bay Area. The valley floor is very flat compared with the hills surrounding the Bay Area. Most of the spillover urbanized areas are surrounded by fertile cropland. The open space provided by row crops provides the new resident a fresh and spacious environment compared with the crowded Bay Area. The attractiveness of environmental amenity and lower housing costs pull many households from the Bay Area.

Because the spillover effects from the Bay Area are expected to continue in the future, urban expansion in the west part of the middle Central Valley will continue. The proper strategy for planners is to facilitate the urban expansion, and try to create efficiently compact urban communities through urban planning. Freeway transportation facilitates the current urban expansion at Vacaville, Antioch and Tracy. And according to New Urbanism, rail transportation tends to generate high density urban communities around rail stations. BART has extended service to Pittsburg on the east and to Pleasanton on the southeast. If BART extended to Vacaville on the northeast, to Oakley and Brentwood on the east, to Tracy on the southeast in 20 or 50 years, intraurban transportation will be well facilitated. For urban expansion, northward continuous expansion should be encouraged in Vacaville, for there are mainly rangelands north of

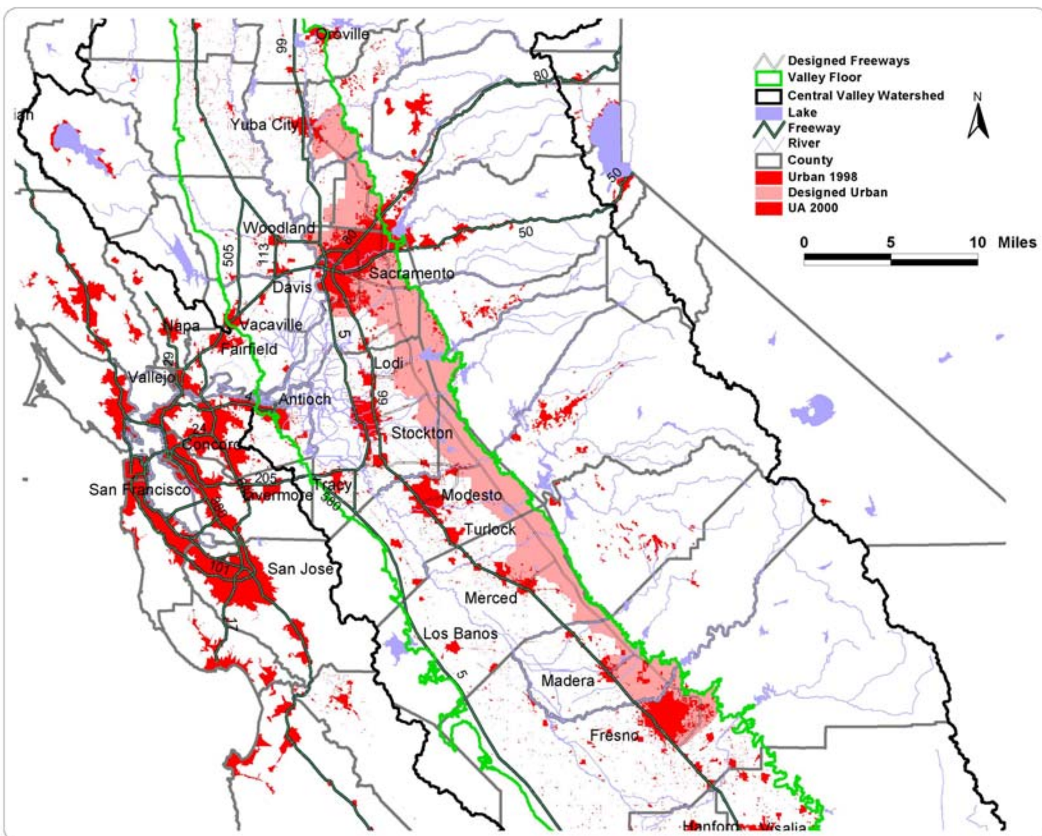
Vacaville, while fertile croplands are located to its east and south. Northward development can save farmland in the Central Valley. Most open space between Antioch and Brentwood is fertile row crops or fruit orchards. For infill growth, farmland loss in this area is unavoidable. A compromise strategy is to take foothill land west for urban development, and thus save some of the farmland. This strategy can be extended to Byron in the south, and finally forms an urbanized zone along the west edge of the valley floor. A similar urban growth strategy can be applied to Tracy. Westward urban expansion should be preferred to eastward urban growth at Tracy for farmland protection and minimizing transportation costs.

Turning east of the Delta area, the urbanized area from Lodi to Stockton and Manteca are surrounded by high value farmland. Especially for Lodi, the surrounding vineyard has very high land value. Urban growth in the past decades has been continuous and compact. Future roadside growth along freeways 5 and 99 should be preferred. Galt is surrounded by rangeland and cropland with lower land value; its urban growth pattern is loose compared with Stockton and Lodi. Infill development should be the major concern for the future land use plan in Galt. Given its physical setting, Galt cannot expect to have vigorous growth, for it is contained by rivers on the north, west and south.

Following freeway 99 south, the urbanized area from Ripon to Modesto, Turlock, and Livingston is surrounded by farmland with high productivity. Their physical settings are similar to the Stockton area, with compact urban growth patterns as well. The difference is that there is a linear urbanized area northeast of Modesto formed by Riverbank and Oakdale. The linear pattern stretches as far as Knights Ferry, which is the east edge of valley floor. The land productivity and land values decrease eastward along this linear zone. The rolling hill terrain on the east edge of the valley floor is rangeland with low land value, and the terrain is flat enough for urban development, so it provides an alternative to urban growth in the high value farmland valley floor. Proper land use and transportation planning can divert the urban growth from the valley floor to the rolling hills, and thus the high value farmland can be saved. The rolling hills are closer to the Yosemite National Park. It is suitable for residential development by view amenities. Eastward urban growth would be facilitated by a freeway extension from route 99 to Oakdale along the south bank of Stanislaus River.

Following route 99 to the south, the physical setting for urbanization changes between Merced and Fresno. Instead of being surrounded by fertile farmland in all directions, the urbanized areas are bordered by rangeland to the east. Theoretically, urban growth should have an eastward orientation, and recent urban growth confirms this result. The medium and large sized urbanized areas in this zone all have unsymmetrical urban growth, and the eastward urban growth is faster than westward. Eastward urban growth takes advantage of lower land costs and proximity to mountain amenities (national parks, skiing, and water sports in reservoirs). Two stages of freeway construction would facilitate eastward urban growth in the future. Stage one is to upgrade current highways linking current urbanized areas to the east edge of the valley floor. Fresno has done for this; the freeway section for route 41 and 168 was extended to the east edge of valley floor. Winton, Atwater, Merced, Chowchilla, and Madera are candidate cities for eastward freeway construction. The second stage is to build a south-northward freeway along the east edge of the valley floor. This would form a linear urban development zone for future development.

For long run urban expansion in the Central Valley, the rangeland and open grass on the east edge of the valley floor between Fresno and Sacramento provides an ideal region 225 km long and 15 km wide on average, and the total area is about 3,375 square km. If the urban population reaches 2,500 persons per square km, this area could accommodate 8.44 million people, which can satisfy the land demand for urban expansion in the this part of the Central Valley at 2050 or beyond 2050. By then, a freeway linking Sacramento and Fresno along the east edge of the valley floor may be needed to facilitate the huge urban expansion on the grassland (Map 18).



Map 18. Strategic Land Use and Transportation Design on the Valley Floor Open Grass Land

A group of medium and small urbanized areas is located south of Fresno, including Visalia, Tulare and Hanford. They are surrounded by high value farmland, and recent urban growth in this area has been continuous and compact. The population density for these urbanized areas is lower than the larger urbanized areas like Sacramento and Fresno. A tough task for local urban planning in this area is to encourage infill growth and increase the population density. The population forecast by DOF shows that the population growth in Kern County is faster than Kings and Tulare County by both absolute population growth and percentage growth, and the absolute population growth between 2000 and 2025 in Fresno County is expected to be 20% more than the sum of Tulare and Kings.

The spillover effect from the Greater Los Angeles dominates urban expansion in the south end of the Central Valley. According to county level census data, 9,000 workers commuted from Kern County to greater Los Angeles in 2000. Bakersfield encountered substantial urban growth on its west side between 1975 and 2000. The spillover effect is expected to continue and become stronger in the southern Central Valley for its relative advantage on land availability compared with the northeast of greater Los Angeles. According to the detailed land use map provided by DWR, the high value farmland concentrates on the edge of the valley floor on the south end of the Central Valley. South of Bakersfield, the farmland on the east of route 99 is fruits and vineyard with high land values, while farmland west of route 99 is row crops with lower land values. The triangular area between interstate 5, freeway 99, and Kern River (Map 19) is ideal for future urban growth. The area available for urban development in this triangle is 320 square km, and can accommodate 640,000 residents with the population density of 2000 persons per square km. A similar size triangular area is available for further urban development west of interstate 5, which can accommodate another 640,000 people. It can be reserved for spillover from Los Angeles beyond 2050.

Five urbanized areas dominate urban expansion in the northern Sacramento Valley, Yuba City, Oroville, Chico, Red Bluff, and Redding. Even through Yuba City is in the influence sphere of Sacramento, spillover effects are weak, because Sacramento is relatively small. Infill growth dominates Yuba City's urban growth in the past decades. Yuba City's urbanized area is actually composed by three cities, Yuba City on the west, Marysville on the east, and Linda on the southeast. Linda is expected to have faster growth because its closer proximity to Sacramento and surrounding farmlands are lower value cropland or rangeland. Yuba City and Marysville are surrounded by high value fruit orchards, and their future urban growth is expected to be slow and compact.

Extension of freeway 65 to the north may need to facilitate the rolling hill urban growth between Marysville and Citrus Heights. And the extension of freeway 65 to the south can link up with the designed rolling hill freeway between Sacramento and Fresno to form a continuous freeway from Marysville to Fresno along the open grass land on the east edge of valley floor (Map 19). The total mileage for designed freeway on the rolling hill (including linkage to freeway 99) is 373 miles, about 10% of California's current freeway mileage (3827 miles in 2001). If the cost for freeway construction is $10 million/mile, total cost is about 3.73 billion, or 74.6 million per year if the cost is split into 50 years.

Oroville is surrounded by low value rangeland, and thus its urbanized area is scattered and the population density is low. Oroville's urban growth between 1975 and 2000 was dominated by infill growth, and proper land use planning is needed for future infill development. The land value difference is dramatic between the east and west sides of Chico. There are mainly fruit orchards on the west, while rangeland dominates the east side. Infill growth dominates Chico's westward urban growth, and leap frog style growth dominates its eastward expansion in recent decades. A proper land use plan strategy for Chico is to contain urban growth on the west, and encourage continuous urban expansion on the east.

Red Bluff is the north end of primary farmland domination in the valley floor. The urban growth between 1975 and 2000 is leap frog style, while the new urbanized area took mainly low valued rangeland. The population density is low. Future urban land use planning should concentrate on creating infill and continuous growth to increase population density.

Redding is at the north end of the valley floor. Most of the valley floor at Redding is rolling hills resulting from fluvial erosion, so cropland is linear along the river bank. Redding is famous for its scattered urbanized area and low population density. Even through some infill growth has occurred, the leap frog pattern has not changed substantially. Although some river bank farmland was urbanized between 1975 and 2000, urbanization mainly occupied rangeland. Redding should seek infill growth, increase urban density, and curb the expansion of the loose urbanized pattern.

After reviewing the Central Valley considering efficient urban growth, we have a general idea of how urban growth in the Central Valley should be through the Neoclassic economic approach. Now we can have some general conclusions concerning optimal urban growth through generalizing the cases discussed in this chapter. Infill urban growth can increase the population density, and thus should normally be encouraged. According the physical setting of the urbanized areas, rangeland should be preferred to farmland for future urban growth for the purpose of farmland protection and efficient land use. Transportation facility setup is critical for a successful land use planning, and thus should be simultaneously planned with urban land use. Vacant land wastes land resources, the urban land use plans should try to minimize vacant lots. Normally, continuous urban growth should be preferred to leap frog development, unless the physical terrain does not allow continuous urban growth. Medium and high mountain urban development should not be encouraged due to high fire risk, construction costs, and transportation costs.

Estimating Water Demand Increase by Rolling Hill Urban Growth

The probe for efficient urban growth results in diverting urban expansion to rolling hill urban growth. This urban growth strategy will transform the linear urban pattern in the Central Valley into a two dimension urban pattern. The central place system trends to mature. And the transportation design is in accord with the transportation principle (K = 4, Figure 3) in the central place theory. Compact urban growth design and farmland protection concerns can secure the agricultural economic base in California. The design is efficient economically. But the rangeland oriented urban growth demands more water than the farmland consuming valley floor urban expansion. For if the urban growth takes mainly irrigated farmland, the water for irrigation can just switch to urban usage without increase the total water consumption, while if the urban growth takes rangeland, the new urban water demand is a net water demand for local water budget, and more water yield is needed to make up the new water demand.

According to DWR's urban water usage survey, urban annual water consumption per acre is 3.2 feet in San Joaquin Valley (DWR, 1998), which is equivalent to the consumptive water usage for one acre of irrigated farmland. The survey needs to be detailed by climate zones and urban land use classes for accuracy, but it can be used as a rough estimation for the urban water demand increase by land use. The estimation is at least an alternative for estimating water demand increase by population growth. And the advantage of land use based water demand estimate is that it indicates the location of the water demand simultaneously.

Table 21. Water Demand Increase for 22 Counties by Trend Urban Growth in 2020

2000-2020	Sqkm	Acres	Water Demand Increase, mill. af	Water Demand, 100 mill. m^3
Crop	1048.8	259161	0.00	0.00
Rangeland	368.5	91049	0.29	3.59
Forest	285.7	70597	0.23	2.79
Fruit	248.8	61483	0.00	0.00
Mining	121.6	30042	0.10	1.19
Other Agri.	18.2	4500	0.01	0.18
Water	12.6	3101	0.01	0.12
Feedlot	7.3	1811	0.01	0.07
Wetland	6.8	1685	0.01	0.07
Sum	2118.3	523432	0.65	8.00

Table 21 illustrates the urban water demand increase estimation for 22 counties in the Central valley at 2020 according to the trend analysis, in which the rolling hill urban development strategy is not applied. For most of the urban growth will take irrigated farmland, the water demand only increases 0.64 million acre-feet (800 million cubic meter) by 2020. Table 22 illustrates the total urban water demand increase estimation for the designed rolling hill urban growth for 2050 and beyond. For the urban growth will mainly take rangeland or open grass, the water demand is much higher than the trend estimation. If the water demand increase is 2.81 million acre-feet by 2050, the water demand increase will be 1.124 million in 2020, 73% more than the trend estimation.

Table 22. Water Demand Increase by Designed Rolling Hill Urban Growth beyond 2050

Land Use Classes	Sqkm	Acres	Water Demand Increase, mill. af	Water Demand Increase, 100 mill. m^3
Rangeland	3494.5	863492	2.76	34.08
Cropland	862.4	213099	0.00	0.00
Urban	439.9	108705	0.00	0.00
Fruits and Nuts	393.7	97276	0.00	0.00
Vineyard	193.3	47762	0.00	0.00
Water	78.3	19355	0.00	0.00
Barren	56.7	14019	0.04	0.55
Homestead	38.3	9463	0.00	0.00
Sum	5557.1	1373170	2.81	34.64

The rolling hill urban growth strategy will not only affect the state wide urban growth pattern, and will affect state wide water supply pattern as while. The increase of water demand in the Central Valley will decrease the water availability to south California form the Central Valley water shed. The urban growth in the Central Valley calls for collaborative statewide urban plan and water plan. If farmland is saved by diverting more urban growth to the rangeland, the urban water demand will take water from environmental water usage, and the stress for Delta Area environmental preservation will increase. Central Valley's urban plan also needs to coordinate with the environmental preservation.

Foot Hill Highway 65 and Wildlife Habitats

In addition to the detail urban growth analysis for major urbanized areas in the Central Valley, the long run urban development at the rolling hills on the east edge of valley floor is a critical conclusion needs to be discussed. The designed grassland freeway from Marysville to Fresno is coincident with Caltrans' plan for Highway 65 extension (Foothill Highway) between Visalia area and Sacramento-Roseville area and SACOG's plan for the Sunrise Expressway linking interstate 80 and freeway 50 (SACOG, 2002). Sacramento beltway has been planned at 1950s and was rejected. But it is revitalized by Sacramento County Department of Transportation's mobility strategies for county corridors study. A six-mile tunnel under Eastern Avenue was proposed by Sacramento County planners to link interstate 80 and freeway 50 recently(Bizjak, 2004).

The planners have common knowledge of future urban growth on the east edge of the valley floor, and this idea has weak conflicts with farmland protectionists. But the environmental preservationists concern about the environmental affects of the east edge urban development. Vernal pools are seasonally flooded depressions found on ancient soils with an impermeable layer such as a hardpan, claypan, or volcanic basalt. They are refuges for native species with agricultural or medicinal properties. They are also important to migrating waterfowl. The rolling foothill designed for urban development is one of the major concentration areas for California's vernal pools. The wildlife habitat will be affected by the expected urban growth. The urban development may conflict with environmental preservation.

It relies on the collaboration between planner and conservatism to resolve the conflicts. Proper urban design is needed to facilitate the urban development and preserve the nature environment simultaneously. Actually, urban development and environmental preservation is not in conflicts absolutely. The vernal pools are not suitable for housing or other urban land use purpose, and thus can be easily preserved. If the major vernal pool complexes are converted into regional park, the wildlife habitat can be preserved in an urban environment. The natural beauty can serve as an amenity factor attracting residential development. Only if the people have senses of natural preservation, man can live with wildlife with harmony. Wetland preservation coexists with urban development in the urban fringe of Chicago is a good example for the man-nature relationship. People want to live adjacent to a lake, and the wetland is preserved while the urban is developed. The local people can enjoy the frog crying and wild duck walking in their backyard. If we think the amenity have value, the value should be relative to human being. A beautiful natural environment has less value for human being unless it is accessible. The amenity value of the vernal pools can be realized only if people have access to them. The critical issue is to preserve them and to utilize them properly, but not destroy them.

Hardwood habitat is another concern by the conservatism. The hardwood belt locates on the foothill east of the valley floor. It has the highest vertebrate species diversity of all vegetation classes in California. Fortunately, the designed rolling hill development zone barely touches the hardwood belt. Spatial analysis indicates that 450 square km or 8% of the designed potential urban area is covered by blue oak, blue oak-pine, or montane hardwood. For shading purpose in the sunny summer, people may prefer to locate their home in the hardwood forest. The planners need resolve another conflict between human and nature. Zoning regulations may need to ban urban expansion into the hardwood, unless there are some proper urban design to protect the hardwood habitat while convert partial of the nature vegetation into residential usage. Very low density urban residential design and awareness of habitat preservation by the residents may a compromise solution.

CHAPTER 11

CONCLUSIONS

Application of a variety of neo-classical urban economic and geographic analytical tools and concepts to California's Central Valley results in the following conclusions.

1. In accordance with the Neoclassic economic theory, urban growth is dominated by consumer behavior, and consumer behavior varies within and among different urbanized areas.

Alonso's household general equilibrium model is largely confirmed through the empirical study in Chapter 5. Wealthier people tend to have larger dwellings located further from central business districts, in suburbs. Thus, wealthier households are a major factor in urban sprawl. The different shapes of the population density curves and housing cost density curves for different urbanized areas illustrate the diversity of human behavior and economic conditions. The lower R square indicates that consumer behavior is difficult to simulate overall. One finding in the single variable modeling is that wealthier households do not use all their extra income on housing for larger space to live. The disposable income remains higher in the suburb, even after higher housing and transportation cost payments. This result implies spending on goods other than housing and transportation.

2. Neoclassic urban economic theory and geographic tools provide insights into the structure of California's network of cities and the internal structure of individual cities in the Central Valley.

Gravity force is based on Neoclassic economic theory. It is applied for urban structure analysis. In Chapter 4, the central place structure is simulated by calculating the gravity forces for urbanized areas in the Central Valley. Various distance decay powers can provide flexibility in model building to fit the real world patterns. The gravity force method for drawing central place boundaries is more flexible than traditional hexagon style central place structure, which applies only to special cases of urban structure. Gravity force is also used for allocating employment and population in the Lowery model. The fitness of Lowery model to real world employment and population allocation can be improved by changing distance decay power. Alonso's concentric zone model is simulated in Chapter 5. The profiles for different urbanized areas illustrate the character of their internal structures.

3. As an automobile dominated society, freeways are always important in determining population density and consumer behavior among the factors investigated.

The consumer behavior is modeled by their accessibility to CBD, edge city, light rail, and interstate highway in Chapter Six. A riverbed dummy variable is added to represent the non-homogonous physical environment. Access to freeway always has the highest t-value in the variables selected. With the size of the Central Valley cities still too small for subway construction, the dominant transportation form remains the freeway.

4. From single variable model to multivariable models, and then to the Lowery model, the fit of models to field data increases.

Even with low R square, the single variable model confirms theoretical concepts of consumer behavior. The multivariable model is an extension of the concentric zone model by treating major transportation structures as extensions of the CBD. The Lowry model is a multi-centric model. Large R square in Lowry model applications imply that the urban population distribution is close to efficient in terms of transportation minimization. The result can be applied in land use planning for better efficiency in urban population allocation. If a Lowery model is used to allocate employment and population to different zip codes, and a multivariable model is used to design detail urban patterns according to the transportation facilities, the resulting urban plan should be fairly efficient.

5. The price of neighboring agricultural land affects the fringe density of urban areas in the Central Valley and the direction of their growth.

Neoclassical theory implies that the low valued land surrounding the urbanized area tends to be urbanized first. Case studies confirmed this theoretical result for Central Valley cities. Tendencies in fringe population density and growth directions can be forecast through investigating their background agricultural land values.

6. The Gross Marginal Density method estimates that the urban area for 22 counties in the Central Valley will be 7299 square km in 2020, a 41% increase from 5181 square km in 1998. The forecast exceeds that of other Logit models.

GMD model expects total population density increases for the urbanized area over time, but the population density increase is weaker than Logit model's estimation. A large gap exists between the result from GMD model and Logit model in 2050. On a comparable base of 15 counties studied, GMD estimates 31% more urban area in 2020 than Logit model. We can not tell if our forecast is accurate. The GMD's forecast can at least call the attention to uncertainty on this subject.

7. These results provide some basis for thinking about desirable urban growth patterns in the Central Valley, and serve as guidance for probing efficient urban growth.

The future urban growth for each urbanized areas is allocated through the idea of efficient urban growth according to the Neoclassic economic principles. Infill and continuous urban development is encouraged, while the leap frog and scatter urban growth pattern is criticized. Proper land use plan and transportation development are necessary to facilitate the urban growth in the Central Valley. Farmland protection is incorporated in the efficient urban growth scheme. Urban growth on the rangeland at the east edge of the valley floor is recommended as a substitution for farmland consuming valley floor urban growth.

8. An effective urban plan calls for the collaborative transportation plan and water plan. And farmland protection and environmental preservation are also critical elements for sustainable urban development.

The urban growth design needs to coordinate with economic structure and population growth. And a successful urban plan needs collaborative transportation plan and water plan. And finally farmland protection and environmental preservation are also important concerns in urban planning. We can conclude that urban plan is actually a comprehensive plan involving nature environment, economic activity, and human behavior. It needs the participation of urban geographer, physical geographer, economists, and social scientist. And the central principle is to better off human beings living conditions by harmony interactive with natural environment and to find a way of sustainable urban growth.

By summarizing the theoretical and application conclusions of the ten chapters in my dissertation, the fundamental conclusion of this dissertation is that the market mechanism is the basic driving forces for urban expansion. As the result of market economy and consumer behavior, the land use conversion is determined by the consumer's choice and land market in the urban fringe. The effective and sustainable urban plan is comprehensive and leads to the harmony relationship between nature and human being.

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By summarizing the theoretical and application conclusions of the ten chapters in my dissertation, the fundamental conclusion of this dissertation is that the market mechanism is the basic driving forces for urban expansion. As the result of market economy and consumer behavior, the land use conversion is determined by the consumer's choice and land market in the urban fringe. The effective and sustainable urban plan is comprehensive and leads to the harmony relationship between nature and human being.

APPENDIX 1. MATHEMATICS NOTES

Alonso-Beckmann's Household General Equilibrium Theory

Part I. The Household General Equilibrium Theory

The household's utility maximizing problem:

$Max\ u(q, r) = U(z(r), q)$

$s.t.\ \ y = z + P(r) \bullet q + k(r)$

U(z, q): utility function

z: money, \$/person; q: space, sqkm/person;

y: income, \$/person; P(r): rent density, \$/sqkm;

k(r): commuting cost, \$/person; r: distance to CBD, km.

Budget constraint $\Rightarrow$

$z(r) = y - P(r) \bullet q - k(r)$

Plug into utility function:

$Max\ u(q, r) = U(y - P(r) \bullet q - k(r), q)$

First order conditions:

$\partial U/\partial q = 0 \ \Rightarrow\ \partial U/\partial z \bullet \partial z/\partial q + \partial U/\partial q = 0$ -------------- (1)

$\partial U/\partial r = 0 \ \Rightarrow\ \partial U/\partial z \bullet \partial z/\partial r = 0$ -------------- (2)

(Note: (2) $\Rightarrow \partial z/\partial r = 0$, i.e. z is constant on r, which is a strong condition)

Budget constraint $\Rightarrow$

$\partial z/\partial q = - P(r)$ ------------- (3)

$\partial z/\partial r = - (\partial P(r)/\partial r \bullet q + \partial k(r)/\partial r) = 0$ -------------(4)

Plug (3), (4) into (1), (2) $\Rightarrow$

$\partial U/\partial z = \partial U/\partial q / P(r)$ ---------- (5)

$- \partial P(r)/\partial r \bullet q = \partial k(r)/\partial r$ ------------ (6)

(6) ⇒ slope of rent-biding curve

$\partial P(r)/\partial r = - \partial k(r)/\partial r / q$ ------------ (7)

Budget constraint and (5) ⇒

$q = (y - z - k(r)) \bullet \partial U/\partial z / \partial U/\partial q$ ------------ (8)

Assume $\partial k(r)/\partial r$ is the same for rich and poor

According to (7) and (8) we have:

y increases ⇒ q increases ⇒$\partial P(r)/\partial r$ increases.

i. e. the rich takes larger space, and the rich has flatter rent-biding curve

Part II. General model for different density function

2.1 The logarithmic density function

The household's utility maximizing problem:

$u0 = z^{a1} \bullet q^{a2}$ $a1 + a2 = 1$

$a2=du0/u0/dq/q$, it is the elasticity of utility with respect to space.

Use the increasing transformation of u0:

$u = a1 \bullet lnz + a2 \bullet lnq;$ $a1 + a2 = 1$

$Max\ u = a1 \bullet lnz + a2 \bullet lnq;$ $a1 + a2 = 1$

$s.t.\ y = z + P(r) \bullet q + h \bullet r$

i.e. assume: $P(r) = A1 + b1 \bullet lnr; D=1/q= A2 + b2 \bullet lnr; k(r) = h \bullet r$

(5) $\partial U/\partial z = \partial U/\partial q / P(r)$ ⇒

$$a1/z = a2/(q \cdot P(r)) \qquad \text{-----------(9)}$$

$$(6)\ -\partial P(r)/\partial r \bullet q = \partial k(r)/\partial r \quad \Rightarrow$$

$$h = q \cdot (-b1)/r \qquad \text{-------- (10)}$$

(9) and (10) $\Rightarrow$

$$z = a1 \cdot q \cdot P(r) / a2 \qquad \text{-------- (11)}$$

$$h \cdot r = -b1/D \qquad \text{---------(12)}$$

Plug (11), (12) into budget constraint $\Rightarrow$

$$y = z + P(r) \cdot q + h \cdot r, \quad a1 + a2 = 1$$

$$y + b1 \cdot q = P(r) \cdot q/a2$$

$$a2 = P(r) \cdot q/(y + b1/D) \qquad \text{-------(13)}$$

2.2 The exponential density function

The household's utility maximizing problem:

$$u0 = z^{a1} \cdot q^{a2} \quad a1 + a2 = 1$$

$a2 = du0/u0/dq/q$, it is the elasticity of utility with respect to space.

Use the increasing transformation of u0:

$$u = a1 \cdot \ln z + a2 \cdot \ln q; \quad a1 + a2 = 1$$

$$Max\ u = a1 \cdot \ln z + a2 \cdot \ln q; \quad a1 + a2 = 1$$

$$s.t.\ y = z + P(r) \cdot q + h \cdot r$$

i.e. assume: $P(r) = A1e^{b1 \cdot r}$; $D = 1/q = A2e^{b2 \cdot r}$; $k(r) = h \cdot r$

$$(5)\ \partial U/\partial z = \partial U/\partial q / P(r) \quad \Rightarrow$$

$$a1/z = a2/(q \cdot P(r)) \qquad \text{-----------(9)}$$

$$(6)\ -\partial P(r)/\partial r \bullet q = \partial k(r)/\partial r \quad \Rightarrow$$

$$h = -q \bullet b1 \bullet A1e^{b1 \cdot r} \qquad \text{-------- (10)}$$

(9) and (10) $\Rightarrow$

$z = a1 \bullet q \bullet P(r) / a2$ -------- *(11)*

$h = -b1 \bullet P(r)/D$ ---------*(12)*

Plug (11), (12) into budget constraint $\Rightarrow$

$y = P(r) \bullet q/ a2 - b1 \bullet q \bullet P(r) \bullet r, \qquad a1+ a2 = 1$

$y + b1 \bullet q \bullet P(r) \bullet r = P(r) \bullet q/a2$

$a2 = P(r) \bullet q/(y + b1 \bullet q \bullet P(r) \bullet r)$ -------*(13)*

2.3 The power density function

The household's utility maximizing problem:

$u0 = z^{a1} \bullet q^{a2} \quad a1+ a2 = 1$

$a2=du0/u0/dq/q$, it is the elasticity of utility with respect to space.

Use the increasing transformation of u0:

$u = a1 \bullet lnz + a2 \bullet lnq; \quad a1+ a2 = 1$

$Max\ u = a1 \bullet lnz + a2 \bullet lnq; \quad a1+ a2 = 1$

$s.t.\ y = z + P(r) \bullet q + h \bullet r$

i.e. assume: $P(r) = A1r^{b1}; D=1/q= A2r^{b2}; k(r) = h \bullet r$

(5) $\partial U/\partial z = \partial U/\partial q / P(r) \qquad \Rightarrow$

$a1/z = a2/(q \bullet P(r))$ -----------*(9)*

(6) $- \partial P(r)/\partial r \bullet q = \partial k(r)/\partial r \quad \Rightarrow$

$h = - q \bullet b1 \bullet A1 \bullet r^{b1-1}$ -------- *(10)*

(9) and (10) $\Rightarrow$

$z = a1 \bullet q \bullet P(r) / a2$ -------- *(11)*

$h \bullet r = -b1 \bullet P(r)/D$ ---------*(12)*

Plug (11), (12) into budget constraint $\Rightarrow$

$y = P(r) \cdot q / a2 - b1 \bullet q \cdot P(r) \cdot r, \qquad a1 + a2 = 1$

$y + b1 \cdot q \cdot P(r) \cdot r = P(r) \cdot q / a2$

$a2 = P(r) \cdot q / (y + b1 \cdot q \cdot P(r))$ -------*(13)*

Part III. Adding a time constraint

Theoretical research is conducted to include time variable in utility function and add a time constraint, this will make the model more complex:

$Max\ u = U(z, q, tr(r), tl(r)),$ U (+, +, -, +)

s.t. $a.\ y = Pz \bullet z + P(r) \bullet q + k(r)$ - Budget Constraint ---------------*(1)*

$b.\ 24 = tr(r) + tl(r)$ - time constraint-------------------*(2)*

$c.\ tr(r) = b \bullet r$ - relationship between tr and r ----------*(3)*

U(z, q, r): utility function;

z: demand for general goods; q: household land area;

y: household income; r: distance to CBD

P(r): housing cost density; k(r): commuting cost;

tr(r): commuting time; tl(r): leisure time

The +, - signs for U function indicates the relationship between the variable in the utility function and the utility, + means positive relationship, - means negative relationship.

Budget constraint: $y = Pz \bullet z + P(r) \bullet q + k(r)$ derives

$z = [y - P(r) \bullet q - k(r)]/Pz$ ---(4)

Assume the budget constraint is always binding, so we can plug (4) into utility function:

$$u = U([y - P(r) \bullet q - k(r)]/Pz, q,, tr(r), tl(r))$$

First order conditions:

$$\partial U/\partial q = \partial U/\partial z/\partial z/\partial q + \partial U/\partial q = 0 \text{-------------------------------------}(5)$$

$$\partial U/\partial r = \partial U/\partial z/\partial z/\partial r + \partial U/\partial tc/\partial tc/\partial r + \partial U/\partial tl/\partial tl/\partial r = 0 \text{---}(6)$$

Budget constraint (1) derives:

$$\partial z/\partial q = - P(r)/Pz \text{--}(7)$$

$$\partial z/\partial r = - (q^*dp/dr + dk/dr)/pz \text{---}(8)$$

Budget constraint (2) and (3) derives:

$$\partial tc/\partial r = dg(r)/dr \text{--}(9)$$

$$\partial tl/\partial r = - dg(r)/dr \text{---}(10)$$

Plug (7) into (5) derives:

$$\partial U/\partial z/Pz = \partial U/\partial q / P(r) \text{---}(11)$$

Equal marginal benefit/marginal cost for z and q

Plug (8), (9), (10) into (6) derives:

$$\partial U/\partial z/Pz = [dg(r)/dr]^* (\partial U/\partial tr - \partial U/\partial tl)/(q \bullet dp/dr + dk/dr) \text{-----}(12)$$

Equal marginal benefit/marginal cost for z and r

Notes:

a. $(\partial U/\partial tr - \partial U/\partial tl) < 0$ is the marginal benefit of increasing one unit of commuting time.

b. $(q \bullet dp/dr + dk/dr)/ [dg(r)/dr] < 0$ is the marginal cost of increasing one unit of commuting time. *$(q \bullet dp/dr + dk/dr)$ must be negative, otherwise people will prefer infinite r.*

c. q*dp/dr is rent decrease per unit of r increase

d. dk/dr is commuting cost increase per unit of r increase

e. dg(r)/dr is converting between increase of r and increase of commuting cost

Finally, (11) and (12) derives Equal marginal benefit/marginal cost for z, r, and q, which satisfies theoretical equilibrium conditions of consumer behavior in Neoclassic economy.

$$\partial U /\partial z/Pz =\partial U/\partial q / P(r) = b(\partial U/\partial tr - \partial U/\partial tl)/(q \bullet dp/dr + dk/dr),\text{----}(13)$$

The left hand side of the equation is the ratio of marginal benefit and marginal cost for z. The middle item of the equation is the ratio of marginal benefit and marginal cost for q. And the right hand side item is the ratio of marginal benefit and marginal cost for r, both nominator and dominator are negative. Combining the 2 first order conditions with 3 constrains a. b. c., we have 5 functions to solve for 5 variables z, q, r, tc, and tl, and the model can be solved theoretically.

APPENDIX 2. MAJOR LAND USE CATEGORIES OF DWR, USGS, AND FMMP

A. USGS, LUDA 1975 categories

1 Urban or built-up land

- 11 Residential
- 12 Commercial and services
- 13 Industrial
- 14 Transportation, communication, utilities
- 15 Industrial and commercial complexes
- 16 Mixed urban or built-up land
- 17 Other urban or built-up land

2 Agricultural lands

- 21 Cropland and pasture
- 22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas
- 23 Confined feeding operations
- 24 Other agricultural land

3 Rangeland

- 31 Herbaceous rangeland
- 32 Shrub and brush rangeland
- 33 Mixed rangeland

4 Forest land

41 Deciduous forest land

42 Evergreen forest land

43 Mixed forest land

5 Water

51 Streams and canals

52 Lakes

53 Reservoirs

54 Bays and estuaries

6 Wetland

61 Forested wetland

62 Nonforested wetland

7 Barren land

71 Dry salt flats

72 Beaches

73 Sandy areas not beaches

74 Bare exposed rock

75 Strip mines, quarries, gravel pits

76 Transitional areas

8 Tundra

81 Shrub and brush tundra

82 Herbaceous tundra

83 Bare ground

84 Wet tundra

85 Mixed tundra

9 Perennial snow or ice

91 Perennial snowfields

92 Glaciers

B. FMMP land use categories

P	Prime Farmland
S	Farmland of Statewide Importance
U	Unique Farmland
L	Farmland of Local Importance
LP	Farmland of Local Potential
I	Irrigated Farmland
N	Non-Irrigated Farmland
iP	Irrigated Pasture
nG	Non-Irrigated Grain
G	Grazing Land
D	Urban and Built-Up Land
X	Other Land
W	Water
Z	Not Inventoried

Prime Farmland (P): Irrigated land with the best combination of physical and chemical features able to sustain long term production of agricultural crops. This land has the soil quality, growing season, and moisture supply needed to produce sustained high yields. Land must have been used for production of irrigated crops at some time during the four years prior to the mapping date.

Farmland of Statewide Importance (S): Irrigated land similar to Prime Farmland that has a good combination of physical and chemical characteristics for the production of agricultural crops. This land has minor shortcomings, such as greater slopes or less ability to store soil moisture than Prime Farmland. Land must have been used for production of irrigated crops at some time during the four years prior to the mapping date.

Unique Farmland (U): Lesser quality soils used for the production of the state's leading agricultural crops. This land is usually irrigated, but may include non-irrigated orchards or vineyards as found in some climatic zones in California. Land must have been cropped at some time during the four years prior to the mapping date.

Farmland of Local Importance (L and LP): Land of importance to the local agricultural economy as determined by each county's board of supervisors and a local advisory committee. See either "A Guide to the Farmland Mapping and Monitoring Program", or the latest copy of the "Farmland Conversion Report" for each county's definition of Farmland of Local Importance.

Grazing Land (G): Land on which the existing vegetation is suited to the grazing of livestock. This category is used only in California and was developed in cooperation with the California Cattlemen's Association, University of California Cooperative Extension, and other groups interested in the extent of grazing activities. The minimum mapping unit for Grazing Land is 40 acres.

Urban and Built Up Land (D): Land occupied by structures with a building density of at least 1 unit to 1.5 acres, or approximately 6 structures to a 10-acre parcel.

Other Land (X): Land which does not meet the criteria of any other category. Typical uses include low density rural development, heavily forested land, mined land, or government land with restrictions on use.

Water (W): Water areas with an extent of at least 40 acres.

Area Not Mapped (Z): Area which falls outside of the NRCS soil survey. Not mapped by the FMMP.

C. STATE OF CALIFORNIA, THE RESOURCES AGENCY, DEPARTMENT OF WATER RESOURCES

Standard Land Use Legend, Land and Water Use Section Statewide Planning Branch, Division of Planning March 1999

1. Agricultural Classes

    G - Grain and Hay Crops

    R - Rice

    F - Field Crops

    P - Pasture

    T - Truck, Nursery And Berry Crops

    D - Deciduous Fruits And Nuts

    C - Citrus And Subtropical

    V - Vineyards

I - Idle

2. Semi-agricultural Class

S - Semiagricultural & Incidental To Agriculture

3. Urban Classes

U - Urban

Ur - Residential

Uc - Commercial

Ui - Industrial

Ul - Urban Landscape

Uv - Vacant

4. Native Classes

Nc - Native Classes Un-segregated

Nv - Native Vegetation

Nr - Riparian Vegetation

Nw - Water Surface

Nb - Barren And Wasteland

5. Unclassified

Ns - Not Surveyed

E - Entry Denied

Z – Outside

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