THE EFFECT OF LAND DEMARCATION ON FARMLAND VALUES IN CALIFORNIA

by

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STATEMENT BY AUTHOR

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I dedicate this Thesis to my parents.

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Abstract

This thesis explores how different systems of land demarcation affect economic performance. Previous literature has established that insecure property rights to natural resources negatively affects the efficiency with which the resource is used. Land demarcation is taken as a physical manifestation of different property rights systems to land. Two land demarcation systems are studied - metes and bounds (MB) and rectangular survey (RS) - in terms of their effect on farmland value, an empirical proxy for economic performance. The MB system is based on random claiming and plotting of land parcels with vaguely defined boundaries. The system of RS is based on a uniform grid of square plots. It is hypothesized that the RS system creates a network and coordination effect amongst landowners thereby helping the land market function more efficiently. An economic framework is developed with predictions that RS areas have higher farmland values per acre and create more incentives to invest in the land. A study of California is carried out using farm data from the 1860 Agricultural Census. It is found that farmland values per acre are lower and there is less incentive to invest in the land in MB regions compared to RS regions. While the results support the thesis, a general conclusion about the state of California is not reached given the data limitations.

CHAPTER 1: INTRODUCTION AND RESEARCH QUESTION

1.1 INTRODUCTION

Demarcating land is an important activity in order to clearly distinguish which piece of land is owned by whom. Part of this activity is to establish a boundary that divides one's piece of land from another's. Boundaries can be human-made or naturally defined by the geography of the land. Unless the owners of adjacent pieces of land mutually agree to accept a common boundary between their lands, there will always be uncertainty on what each land owner considers as their own.

The ability to distinguish one's piece of land from another's allows one to undertake their desired land uses with a sense of security. A well-defined boundary could be considered to be a physical manifestation of the extent of property rights to a certain piece of land. Economic efficiency in resource use is found to be highly consonant with clearly defined property rights- a fact well established in the literature (Mendelsohn 1994; Besley 1995; Alston, Libecap and Schneider 1996; Jaffe and Louziotis 1998). What is lacking in this literature is a linking of land demarcation systems and economic performance. Libecap and Lueck (2009b) argue that land demarcation is fundamental to property law because as an institution, demarcation offers information to land owners, and accordingly shapes their incentives for economic behaviour.

In this thesis I examine the effects of two different land demarcation systems on economic performance. I use farmland values in 1860 California as an empirical proxy for economic performance. The two land demarcation systems are the metes and bounds system (MB) and the rectangular survey system (RS). According to Hinkel (2000) an MB description sets forth and completely describes the boundary lines of the land and each individual land owner decides the shape and boundary pattern. Metes are the measurements or distances and bounds are the boundaries. An MB description gives the distance and direction of each boundary line of a parcel of land by starting at a beginning point and tracing all the way around the parcel up to that point. Bone (2006) provides an example of an MB description of a parcel of land near Mt. Diablo in California.

> "*Begin at a point 30 feet north of the southwest corner of section 18 Mt. Diablo B. & M, then north 36 feet, then N. 89/35`E. 210. 14 feet, then S. 36 feet, then N. 89/35`E. 210 14 feet, then S. 36 feet, then S. 89/35`W. 210. 14 feet to beginning.*"

Distances and directions are sometimes absent from MB parcel descriptions. References are made to temporary features such as trees and other natural features, which are probably only locally known and understood. Hornbeck (1978) provides the following description of a Rancho San Andres in Santa Cruz County, California covering a total of 8912 acres.

> "*... on the side of the east, the boundary is the canada called del Cierbo, and on that of the north from the point where the bolsa commencing as far as the canada, which is called San Antonio, at a point at which a live oak stands which is outside the same, and is the boundary of the two sitios. This live oak stands on the edge of the plain on the left from south to north to the left, where there is a sheep corral which formerly belonged to the Mission of Santa Cruz.*"

Under RS individual surveys are governed by standardized measurement methods, parcel shapes and alignment. It is administered by a central agency that references a geographical-based address rather than natural features of the land (Libecap and Lueck 2009a). Figure 1.1 is a satellite image highlighting the differences between the two demarcation systems used in the US and Mexico at the border in Yuma, Arizona. The MB system is to the left half and the RS system is adjacent to the right.

FIGURE 1.1: MB AND RS SYSTEMS ADJACENT TO EACH OTHER AT THE MEXICO-US BORDER AT YUMA, AZ (LOCATION: YUMA, AZ 32°N, 114°W). Source: Google Earth (2009)

Under MB, property boundary surveys are not required to occur before settlement and individual land claimants would try to capture as much valuable land and minimize demarcation costs by using natural features as boundaries (Libecap and Lueck 2009a). Most often one will note the reference made to natural features that may not be permanent. This also gives rise to vague definitions that are mostly only locally understood and often not agreed upon by neighboring property owners. By contrast the RS system incorporates standardized measurement methods, parcel shapes and alignment. For instance, in the US Rectangular System land is divided into six mile by six mile square townships with north-south lines intersected by perpendicular east-west lines (Dukeminier and Krier 2002). Townships are further divided into 36 sections each 1 mile square and numbering from 1 to 36 starting with 1 in the northeastern section and running north to south in each row up to 36 in the southeast section (see figure 1.4). Uniformity in boundary definition gives rise to clarity in demarcating what piece of land belongs to which owner. Boundary surveying costs are borne upfront by the surveying authorities and thus individuals who come later to settle on these square pieces of land are saved this cost (Libecap and Lueck 2009a).

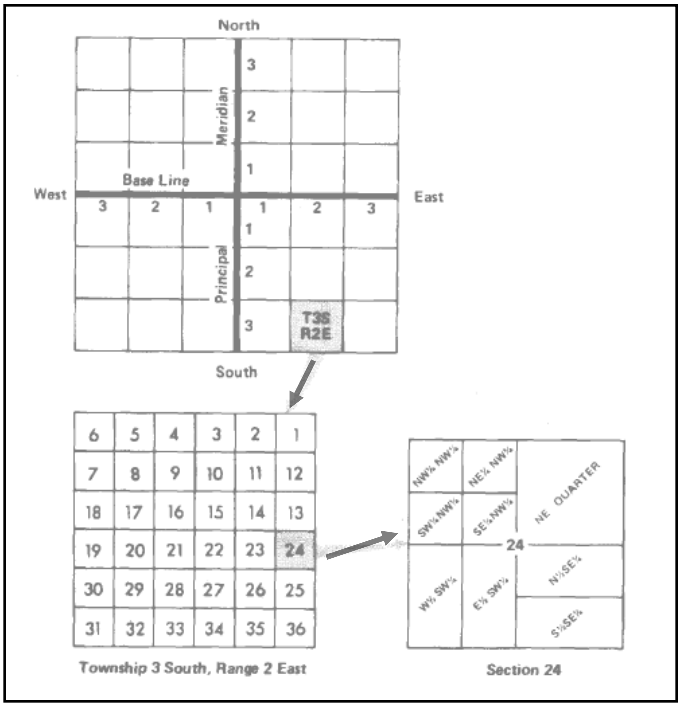

FIGURE 1.2: RECTANGULAR GRID STRUCTURE OF THE US PLSS.
Source: Hornbeck, 1976.

MB is decentralized with individuals demarcating their plots themselves, whereas the RS is a centralized and coordinated one in which all parcels are connected (Libecap and Lueck 2009b). Libecap and Lueck (2009b) further argue that MB does not generate any network effects amongst land owners in order for them to coordinate demarcation and their land uses. The RS however does create a network effect and allows land owners to coordinate their actions by relying on standardized methods. These differences between the two land demarcation systems allow one to study how these institutions affect economic performance.

Literature on the topic of property rights and economic behavior has established that security of the former is important for the latter. Libecap and Lueck (2009b) take this area of research one step further by studying the effects of land demarcation systems on economic performance. The network and coordination aspects of land demarcation systems affect the security of property rights and also the functioning of land markets (Libecap and Lueck 2009b).

1.2 Research question

In this thesis I examine the effects of two land demarcation systems on farmland values in nineteenth century California. The two land demarcation systems in the state- metes and bounds and rectangular survey- provide the setting for a natural experiment to study demarcation effects on economic performance. The areas demarcated under metes and bounds were essentially the ranchos of the Spanish and Mexican eras in California. The US Rectangular Survey system was used to demarcate land not covered by the ranchos. Hence there is a natural experimental setting for studying the economic performance of areas covered by the two demarcation systems.

An economic framework is developed to account for the cost of boundary demarcation and enforcement for farmers under each demarcation system. I also incorporate insecurity faced by each farmer in terms of both property boundaries and land title. With the characteristic imprecision and vague nature of an MB system, as opposed to the more systematic rectangular survey system, there is the likelihood of property boundary disputes. This is likely to lead to lowered incentives for the owners of such property to invest in it and maintain it- thus lowering land value. Libecap and Lueck (2009a) argue that the RS system lowers the costs of land development and exchange through its measurement, enforcement, and incentive effects as opposed to the MB system. They also note that RS generates a public good information structure that expands the land market. With an expanding land market and lowering transaction costs it becomes cheaper for parcel reorganization when market conditions change. Hence it is argued that this leads to an increase in the value of land per acre.

My empirical analysis uses data from nineteenth century California to examine the initial effects of land demarcation systems derived from the Spanish, Mexican and US governments chronologically. When California was under Spanish control, land demarcation was usually defined to cater to large tracts with some degree of uniformity in the dimensions and land use conditions. Under Mexican control, these large tracts were internally subdivided in random ways- usually using the MB system of demarcation. When the US took over California in 1848 the rectangular system began to be extended into the rest of the state's lands. This historical setting led to the creation of two distinct sets of land demarcation and thus allows me to study their effects on farmland values.

1.3 Organization of Chapters

This thesis is organized as follows. In chapter 2, I describe the history of land demarcation in California under the Spanish, Mexican and US institutions. In chapter 3, I develop an economic framework for land demarcation and its hypothesized effects on land value. In chapter 4, I describe the empirical strategy and the analysis empirical study using the data collected. Chapter 5 gives a summary of the results and remaining questions for future research.

CHAPTER 2: HISTORY OF LAND DEMARCATION SYSTEMS IN CALIFORNIA

In Chapter 1 I discussed the two systems of land demarcation and the potential differential affects they may have on farmland value. This chapter discusses the history of land demarcation in the state of California. The state had three phases of land demarcation respectively under the Spanish (1500s to 1821), Mexican (1822-1848) and US governments (1848-present) (Morris 1994). It is important to understand these land demarcation institutions because the land tenure laws of the different governments manifested themselves in very different ways.

2.1 SPANISH ERA (1500S TO 1821)

The Spanish occupation of California began in the 1500s (Morris 1994). In 1781 the *Reglamento* formed the legal basis of settlement, colonization and ownership of land in California (Gaffey 1975). The King of Spain was the owner *in fee simple* of all colonial property and the land's resources. The King gave grants for very large tracts of land, which laid the foundation for three forms of settlement- *presidios*, *pueblos* and *missions*- meant for colonization purposes.[1]

Private land grants only began to be given out in 1784 by Governor Pedro Fages in the Los Angeles area (Robinson, 1948). Veterans of the Spanish Army petitioned the Governor for very large unoccupied tracts of land outside of *presidio* and *pueblo* boundaries to be used for rearing cattle and horses; these land grants came to be known as *Ranchos*. One private grant was as large as 300,000 acres today the area covers

[1] *Presidios* were military posts formed to defend a province against foreign invasion. *Pueblos* were towns built with provisions for plazas, churches, public buildings, orchards for each settler and a communal pasture. *Missions* were land grants to be used by friars to Christianize the Indians and the King of Spain placed large tracts of land at the friars' disposal.

Huntington Beach, Long Beach, Norwalk and Downey in the Los Angeles metropolitan area (Robinson, 1948). Thirty such private land grants were made during the Spanish era.

Presidios, *pueblos* and *missions* had a certain degree of uniformity in dimension and shape of parcels set aside for settlement (Morris 1994). The individual private land grants' were left to be settled individually and their boundaries demarcated according to the discretion of the owners (Robinson 1948) - characteristic of the metes and bounds system.

2.2 MEXICAN LAND DEMARCATION (1821-1848)

With the overthrow of Spanish rule in 1821, the public domain passed into the Mexican Republic's hands. The government was faced with the problem of filling several empty lands with people (Corbett 1959). To encourage settlement in the northern frontier and stimulate agricultural development the Mexican government liberalized the nation's land policy (Hornbeck 1976).[2] According to Robinson (1948) Mexican governors were given the authority to grant vacant lands to "contractors (*empresarios*), families or private persons, whether Mexicans or foreigners, who may ask for them for the purpose of cultivating and inhabiting them."

The Colonization Act of 1824 and the Supplemental Regulation of 1826 facilitated the rapid disintegration of the mission-controlled communities. This made available over 10 million acres of land to Mexican citizens and foreigners for the purposes of settlement, cattle ranching and cultivation (Gaffey 1975). Settlers who were previously living in presidios and pueblos took advantage of this granting of land by the government (Robinson 1948). Ranchos were also being carved out of previously held

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2 In a parallel of US land policy, Allen (1991) details out how public land was transferred into private hands and argues that when the US government was faced with the problem of settling the West, the Homestead Policy of first possession was actually an efficient process.

mission lands. A total of 750 grants were made covering a total area of more than 12 million acres (Clay 2006). The location of all the land grants is shown in figure 2.1.

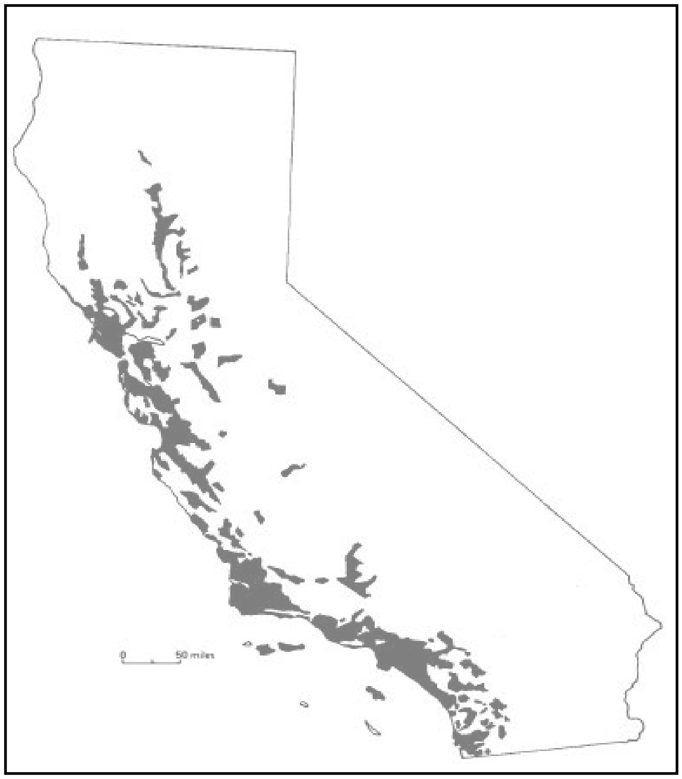


FIGURE 2.1: SPANISH AND MEXICAN LAND GRANTS IN CALIFORNIA. Source: Hornbeck (1976).

The settlers used the metes and bounds method of demarcating the boundaries of the ranchos. Applicants for land grants had to petition the governor for a piece of land with requisite documentation. Amongst other things these documents had to include a description of the land by a hand-sketched map (*diseño*) of the boundaries and the land's natural features. The map and land description were usually vague because they called to sloughs, trees, hills, and other features which were not very permanent. The governor would send these documents to local officials, who would verify that the land was indeed vacant. The governor would then issue a formal land grant in writing to the applicant.

The metes and bounds demarcation system was also used to demarcate plots within the ranchos. For instance, a certain Mr. Mariner was granted land in the Los Angeles area- circa 1840- known as Rancho *Rincon de San Pascual*. It was bounded by the mission San Gabriel, the Sierra and the Arroyo Seco. The governor who eventually granted formal possession had to ensure it was surveyed in accordance with the ordinance for marking boundaries- essentially a metes and bounds system. Mariner could enclose this property but with no detriment to crossways, roads and servitudes. Chain-bearers and amateur surveyors proceeded on horseback around the boundaries of this rancho using a cord 0.052 miles long, each fastened to a wooden stake and placing proper land marks as they proceeded. The boundaries were marked out at the limits with land markers and fruit trees enclosing an area of 2,880 acres (Robinson 1948). Figure 2.2 below shows the corresponding *diseño* hand-drawn by Mariner and submitted to the governor.

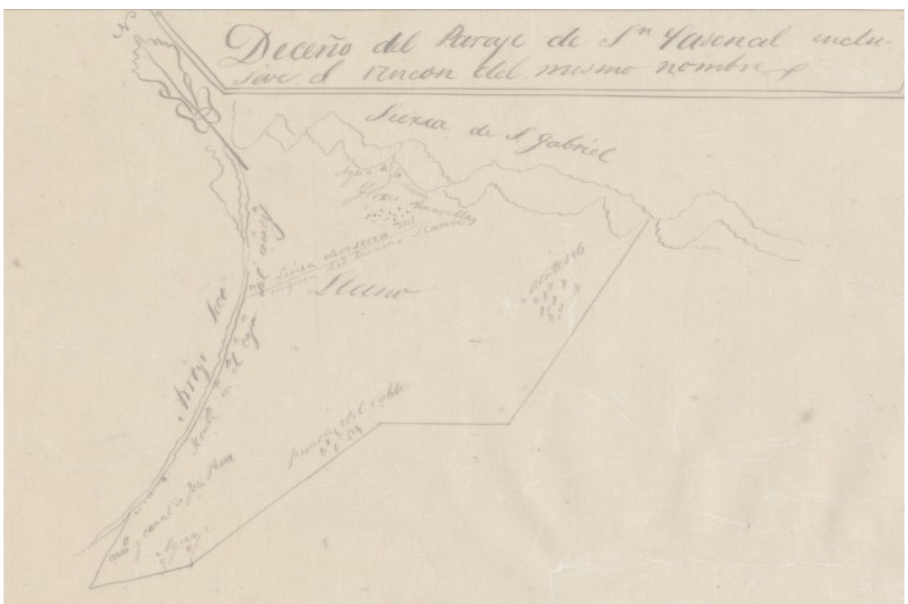


FIGURE 2.2: *DISEÑO* OF RANCHO *RINCON DE SAN PASCUAL* IN THE LOS ANGELES AREA. Source: Land Case Map A-1113, Bancroft Library, UC Berkeley.

A few years into the Mexican era, ranchos began to be sub-divided and sold. For this the buyer and seller had to have a deed drawn up before an *Alcalde* (officer with notary power). The *Alcalde* had to certify all facts about the conveyance including the names of the parties, the words of the conveyance, a description of the property being conveyed and the warranties involved.

However, there was an almost complete absence of professional surveyors. Residents of the time had a certain laxity in attending to legal details which resulted in vague and non-uniform land descriptions. The larger rancho boundaries were demarcated by the MB method and so were the internal subdivisions in several cases. Population in the pueblos of Sonoma, San Francisco, San Jose, Monterrey, Santa Barbara, Los Angeles and San Diego grew rapidly and several towns were carved out of what was previously rancho land. The internal subdivision and selling of such private property were not restricted by law and even town lots did not require professional surveying. Plot descriptions included references made to natural features some of which were not permanent- like trees, groves and streams. Boundary disputes were common during the Mexican era. For example, in 1840 Mr. Martin was granted land in Marin County. Later in 1844 Mr. Mesa was granted an adjacent plot and, despite coming four years later, accused Mr. Martin of building on his portion of the land.[3]

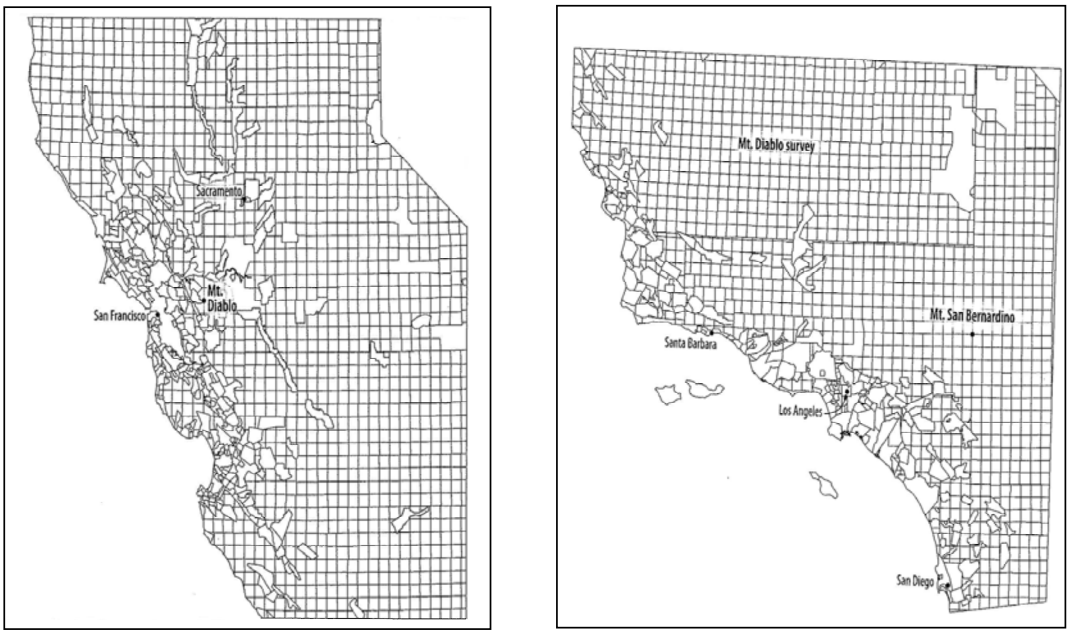
The granting of land by the Mexican government came to an end in 1846 because of American westward movement into California during the Gold Rush.

[3] Source: http://www.co.marin.ca.us/depts/lb/main/crm/maps/index.html accessed on 14th May 2009.

2.3 US Land Demarcation Era in California (1848- Present)

The US took over from Mexico in the year 1848. After the organization of the California state government by the US, Congress provided for the survey of federal lands to cater to the increased demand for land. In 1853 an Act provided for a Surveyor General in California to survey private land claims and federal lands (Robinson 1948). This facilitated the identification of lands so they could be readily transferred by the US to the state and private individuals. The rectangular survey system's extension into the state brought with it the benefits of the Land Ordinance of 1785 (Linklater 2002). Townships were to be located in 6 mile square land areas with 36 one square mile sections. According to this system, land could be passed from the public domain to individual ownership through various laws that regulated land price and the amount of land to be sold (Hornbeck 1976). Settlers could obtain land under the Pre-Emption Act, the Homestead Act, Desert Land Act and other Acts. Precise surveyed boundaries and easily accessible legal documents relating to land transactions were common features of these US land tenure laws (Hornbeck 1976). Where the Spanish and Mexican land grants came up, the portions lying in the ranchos were omitted from the townships.

In the entire region covered by the Treaty of Guadalupe-Hidalgo, California was the quickest to establish a framework for measurement (Linklater 2002). Principal Meridians and Base Lines were established in the state. External boundaries of ranchos had to be surveyed prior to the US rectangular surveys. The US assigned Deputy Surveyors with the task of establishing these boundaries. Federal land, meanwhile, had begun to be subdivided in California using the rectangular system. The Surveyor General of California suggested that three Initial Points be established in California to cater to the steepness of terrain.[4] These were placed at Mt. Diablo in Contra Costa County in 1851, San Bernardino Mountain in San Bernardino County in 1852 and Mt. Pierce in Humboldt County in 1853. Figure 2.3 shows where the land not covered by Ranchos was divided up according to the US Rectangular Survey method.



A) Mt. Diablo Meridian B) San Bernardino Meridian

FIGURE 2.3: THE US RECTANGULAR SURVEY AND THE SPANISH LAND GRANTS IN CALIFORNIA. Source: Hubbard (2009).

In figure 2.4 one can see an example of how large ranchos were subdivided using MB and the RS filled in the remaining land area. The current day satellite photo shows that MB is still prevalent in California.

[4] Source: http://www.mdia.org/mdiaipt.htm

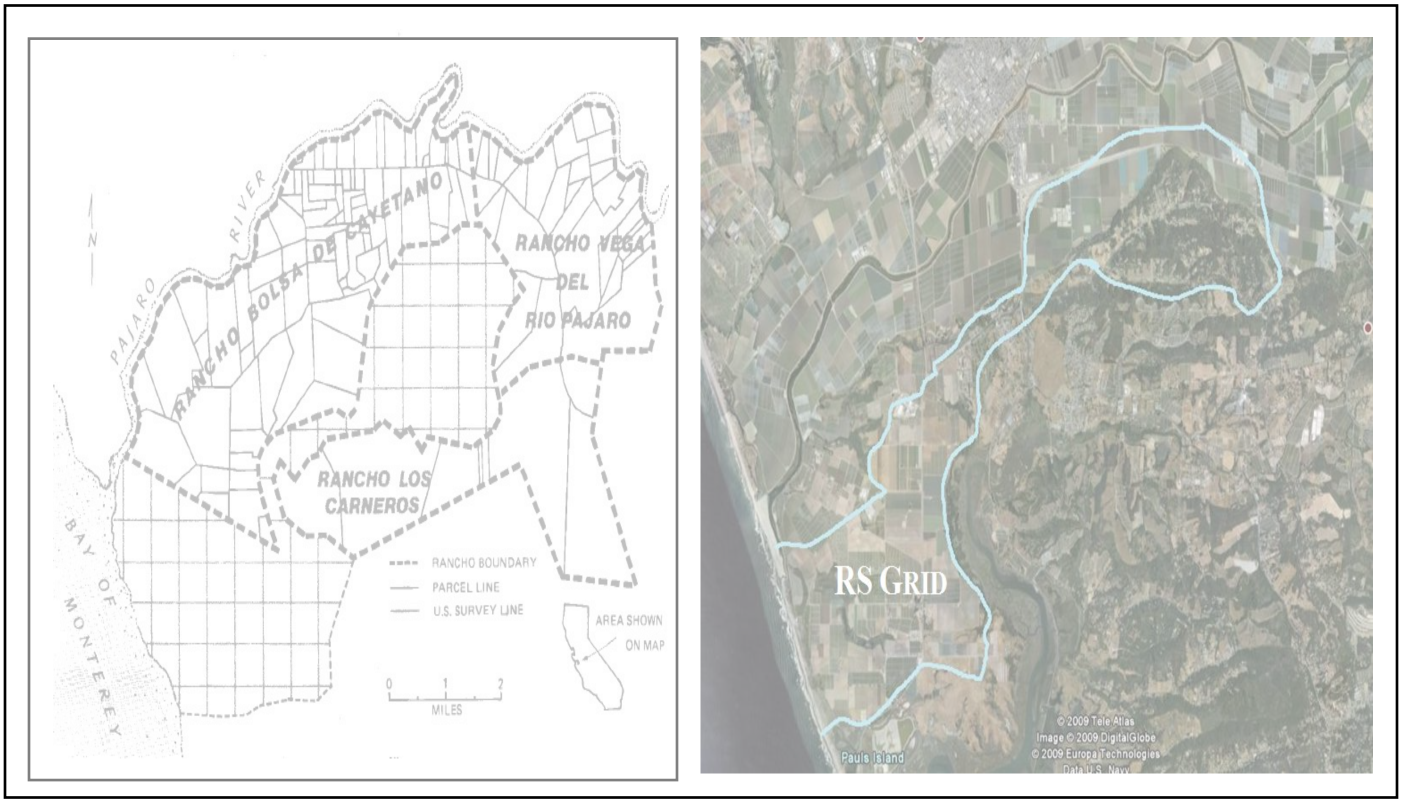


FIGURE 2.4: PATTERNS OF LAND DIVISION IN THE MONTERREY BAY AREA OF CALIFORNIA. Source: Hornbeck (1976) and Google Earth (2009).

When California was taken over in 1848 there was a flood of American settlers. What was needed was a segregation of privately claimed lands, with ownership dating from the Mexican period, from the lands that were now part of the public domain (Robinson, 1948). As per the Treaty of Guadalupe Hidalgo the US had to recognize "legitimate titles to every description of property, personal and real, existing in the ceded territories." (Gaffey 1975). In 1841 the Preemptive Act of the US gave the first chance to squatters on surveyed public land to purchase land at $1.25 per acre. Between 1853 and 1862 they were allowed to preempt on un-surveyed land in several states including California, Oregon, Washington, Kansas, Nebraska and Minnesota (Allen 1991).

The westward moving Americans were used to their own land tenure laws. The settlers who were not lucky to strike gold during the Gold Rush wished to acquire homesteads in the fertile farming lands further west near the coastal valley (Gaffey 1975). However, most of the good agricultural land was already taken up by the Mexican land grants (Clay 2006). Table 2.1 shows how the state population was growing rapidly, which contributed to increased land demand (Hornbeck 1979). Where ranchos were encountered, disputes arose and created confusion as to which lands were available for settlement or not (Hornbeck 1976).

TABLE 2.1: POPULATION GROWTH IN CALIFORNIA (1850-1890)

Year	Population
1850	92,597
1860	379,994
1870	560,247
1880	864,694
1890	1,213,398

Source: US Census Bureau data (1850-1890).

To confirm titles to private land grants, the California Land Act was passed in 1851. The provincial records of Spanish and Mexican governments, such as land deeds and sketch maps, were to be examined by a Board of Land Commissioners who had to adjudicate private land claims. The new law placed the onus of proving title on the claimants, but appeals could also be made against the Commission’s decisions to the

District Courts and from there to the US Supreme Court. Land claims were encumbered by costly legal processes. The time taken to receive a final patent took up to forty years and all costs had to be borne by the applicant. Litigation processes took several years to complete and eventually only 604 of the 750 claims were eventually approved by the Board of Land Commissioners.[5] The time taken from submission of initial claim to receipt of patent took on average about 17 years (Hornbeck 1979). If a claim was deemed valid by the court, then the next step involved surveying of the claim and resolving of boundary disputes. When a claimant could not provide adequate evidence to prove title to the land claim, it was rejected and then became part of the US public domain and opened up for settlement (Hornbeck 1979).

Having discussed the land demarcation history of the state of California, I now shift the focus on answering my research question. In the next chapter I develop an economic framework from which I derive predictions about the effects of land demarcation on economic performance.

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[5] Source: http://www.sos.ca.gov/archives/level3_ussg3.html accessed on May 14th 2009.

CHAPTER 3: ECONOMIC FRAMEWORK

In this chapter I develop an economic framework that incorporates the link between economic performance and property rights. This framework allows for a comparative analysis of the RS and MB demarcation systems. Drawing largely from the economic framework developed in Libecap and Lueck (2009b) I analyze how the RS system generates different incentives for economic performance- specifically the efficiency of land use.

3.1 MODEL SETTING AND ASSUMPTIONS

I begin by examining the case where a given number of farmers claim and enforce separate plots in order to maximize their individual farmland values or net profits. Assume that each farmer has access to the same level of farming technology. Assume these farmers claim and enforce within a large rectangular piece of land of dimensions six by twelve miles. Assume the land is flat and homogenous in its soil quality. Allow one half of the land to be demarcated, prior to any settlement, using the centralized RS system and the other half to be demarcated individually by farmers using the MB system.

The piece of land demarcated by the RS system has thirty-six square miles of area, which allows thirty-six square sections, each one mile square, to be demarcated by a centralized survey agency. Centralized demarcation results in each of the thirty-six sections being aligned uniformly in a north-south direction. It also results in a coordinated network of land parcels with the boundaries being clearly demarcated upfront. The benefits of the network effect appear in the form of avoided costs of boundary enforcement by the individual farmers; all the other farmers in this system also have their plot boundaries demarcated by the centralized surveying agency. The farmers who settle within the RS half can subdivide their plots into smaller square or rectangular sections and sell them. The land market is allowed to function efficiently with almost no uncertainty as to which parcel belongs to whom, as well as little or no disputes on plot boundaries between adjacent land owners. Farmland owners in the RS half are thus able to carry out their economic activities with almost no boundary uncertainty.

In the MB half farmers will likewise claim and enforce parcels of land. However, with the individualistic MB system, there is no coordination among land owners in terms of parcel alignment and dimensions. Libecap and Lueck (2009b) argue that individuals demarcating on a flat and homogenous piece of land will choose rectangles as their boundaries so as to avoid having to waste gaps in between parcels. Assuming this to hold true, farmers would choose rectangles as their parcel shapes. But without any coordination amongst land owners there will be little or no network effect benefits as is seen in the RS system. Because the farmers in the MB half demarcate their plots individually, this leads to greater boundary uncertainty, since one farmer’s boundary may not be agreed upon by the adjacent farmers. With little or no coordination in alignment amongst the MB parcels some fraction of the farmers settling on the MB half may begin demarcating rectangles as their own plots with a particular alignment, whereas another fraction of farmers will choose another alignment.

One possible scenario that may result is seen in Figure 3.1. This figure is a schematic with the MB demarcation of parcels to the left half and RS demarcation of parcels to the right half of the six by twelve miles large rectangular piece of land. The RS half is seen to be uniform in terms of parcel dimensions, alignment and shape. The MB half has parcels with no uniform alignment and dimensions. Although rectangles are the chosen shape of these farmers, it is seen that without uniform alignment, triangular parcels get formed when different sets of farmers' parcels collide at odd angles.

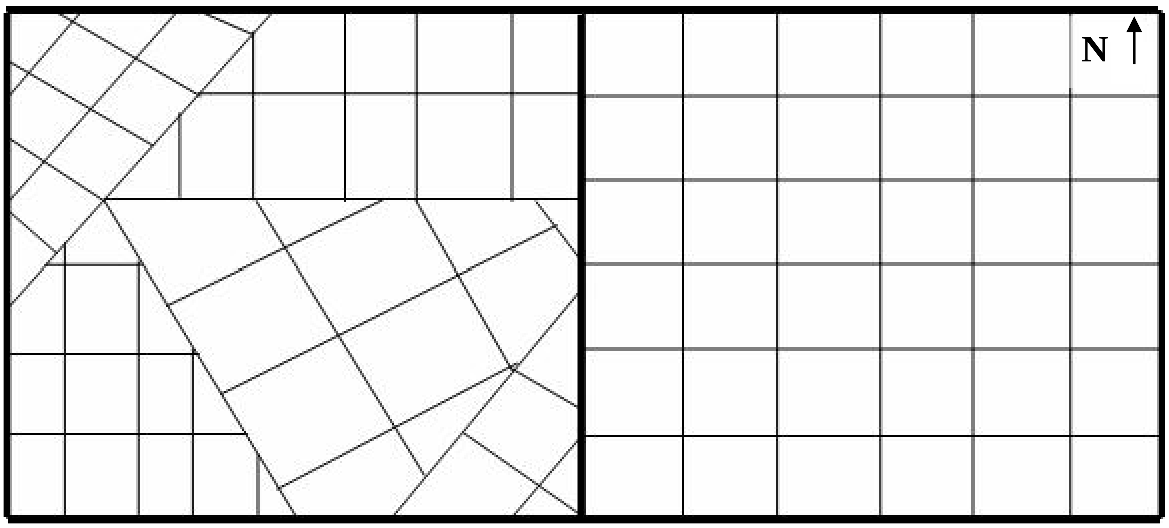

FIGURE 3.1: SCHEMATIC OF ADJACENT MB (LEFT) AND RS (RIGHT) LAND DEMARCATION SYSTEMS.

According to this theoretical setting farmers can choose to settle in either one of the halves and then demarcate by MB or RS systems. Demarcation entails choosing the optimal land area that would be required for the farmer's land use activity. Farmers in the RS half would choose optimal acreage by subdividing their square plots or purchasing further square sections from the land market. Farmers in the MB half choose optimal acreage in rectangular shapes and in some instances choose very large parcel sizes. Adjacent land owners may also have a similar aim and choose large acreage. Then there is the possibility of dispute when trying to decide upon common boundaries. This leads to uncertainty of boundary and consequently insecure property rights to land; some proportion of the farmers' lands is thereby unusable for economic activity.

3.2 Theoretical Model

In the above setting each farmer (i) maximizes farmland value or net profit function (Π_i) for a given acreage of farmland. Profit is taken as revenue from output produced ($r_i\ (q_i, t_i, f_i).s_i$) net of production costs ($c(q_i)$). Profit is maximized by the individual farmer with q_i as the choice variable.

$$\max_{(q_i)} \Pi_i = r_i\ (q_i, t_i, f_i).s_i - c(q_i) \tag{3.1}$$

Boundary uncertainty of land parcels is represented by s_i which assumes values between 0 and 1. As s_i tends to 0 it implies greater boundary uncertainty and the opposite holds as s_i tends to 1. It is assumed that boundary uncertainty affects the revenue from production- thus with no boundary uncertainty (i.e. $s_i = 1$) the farmer can produce and sell the entire profit maximizing quantity, and as s_i decreases, the farmer would be able to sell less than the profit maximizing quantity.

Revenue (r_i) is a function of quantity produced (q_i), ruggedness or topographical characteristics (t_i) and soil fertility (f_i). Topography and soil fertility are taken to be exogenous to the farmer and affect revenue with the following assumptions-

$$r_q>0,\ r_{qq}<0$$

$$r_t<0,\ r_{tt}>0$$

$$r_f>0,\ r_{ff}<0 \tag{3.2}$$

Production cost c_i is a function of the quantity produced and increases in q_i at a decreasing rate-

$$c_q>0,\ c_{qq}<0 \tag{3.3}$$

The schematic in figure 3.1 is a naturally occurring experiment wherein one can study the economic behavior of farmers under different demarcation systems, which are adjacent to each other. The farmer can settle either in the MB or RS halves- each system with their own associated parcel dimensions, shapes and alignments. Parcels in the MB half are associated with greater boundary uncertainty- i.e. lower values of s_i.

Each farmer individually maximizes equation 3.1 and solves for q_i* in partial equilibrium. The first order condition is-

$$\partial \Pi_i / \partial q_i = r_q . s_i - c_q = 0 \qquad (3.4)$$

The second order condition is accordingly-

$$\partial^2 \Pi_i / \partial q_i^2 = (r_{qq} . s_i - c_{qq}) < 0 \qquad (3.5)$$

Solving 3.4 gives us the profit maximizing q_i^* which can be plugged back into 3.1 to give us the profit maximum Π_i*.

$$\Pi_i^* = r_i(q_i^*, t_i, f_i) . s_i - c(q_i^*) \qquad (3.6)$$

The maximum profit per acre is derived as $V^* = (\Pi_i^*/h_i)$, where h_i is the fixed acres of farmland for each farmer. Empirically V^* is represented by farmland value per acre. The theoretical predictions are now laid out.

3.3 PREDICTIONS

Prediction 1: *RS farms will have higher per acre farmland values than MB farms*.

In the above setting RS farms have less boundary uncertainty compared to MB farms and are thus have values of s_i closer to 1. Differentiating V^* with respect to the parameter s_i yields the first prediction.

$$\partial V^* / \partial s_i = \partial(\Pi_i^*/h_i)/\partial s_i = \partial(r_i(q_i^*, t_i, f_i) . s_i - c(q_i^*))/ h_i . \partial s_i$$

$$= r_i(q_i^*, t_i, f_i)/ h_i > 0 \qquad (3.7)$$

The sign of this derivative is positive based on the assumption that the maximum revenue per acre is positive.

The next set of predictions relate to incentives to invest in farmland improvements, uniformity of parcel dimensions and demarcation system viability in varied topographies. These predictions follow largely from related literature on the subject of land demarcation, property rights and their effects on land use and value.

Prediction 2: *MB farms will have greater proportion of unimproved farmland*.

This prediction is based on the assumption that MB farms are associated with greater boundary uncertainty, which is a physical manifestation of insecure property rights. Feder *et al* (1988) argue that farmers' incentive to invest in agricultural improvements is hindered by insecure land title.

Prediction 2 is also essentially a corollary of Prediction 1. By virtue of MB farms having greater boundary uncertainty (lower s_i) there will consequently be lower V^*. MB farms would be associated with lower profits or farmland value per acre and this negatively affects the incentives for the farmer to invest in farmland improvements.

Prediction 3: *MB farms will have greater variation in farm size*.

In MB the parcels or farms are demarcated and enforced individually and not prior to settlement by a centralized agency, unlike under RS where surveys are done prior to settlement. Each farmer maximizes his or her farmland value as given by equation 3.1. The RS system leads to uniformity in the size of parcels. In RS the land market functions more efficiently because of the aforementioned coordination and network effect benefits.

Prediction 4: *There are diminishing returns associated with RS in more rugged terrain as compared to MB.*

This prediction draws from Libecap and Lueck (2009b) where it is assumed that if land value, demarcation and enforcement costs depend on terrain ruggedness, then one can expect the boundaries to follow the topography of land. Figure 3.2 is a schematic depicting how rugged topography diminishes the returns to RS.

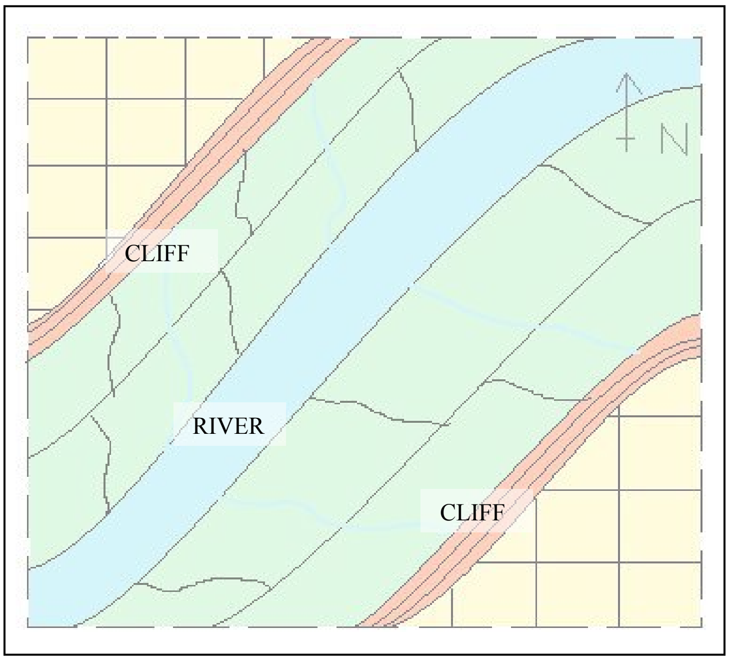

FIGURE 3.2: IMPOSING RS ON EXTREME TOPOGRAPHY IS COSTLY.
Source: Libecap and Lueck (2009b).

The cost of demarcating and enforcing using the RS system in rugged terrain becomes excessive. At the top of the two cliffs in figure 3.2 the land is flat and imposing the RS system is feasible. Once the cliffs are reached, then trying to impose the rectangular system is no longer feasible. Thus where the terrain becomes rugged it makes better economic sense to demarcate using the MB system.

The next two predictions relate to the effects of exogenous factors that affect farmland value. These predictions essentially follow from the assumptions of the model.

Prediction 5: *Farms with better soil fertility have higher per acre farmland value*.

This prediction is essentially a control variable prediction, as are the next two predictions. The predicted effect of soil fertility on farmland value follows from equation 3.2, i.e. $r_f > 0$.

Prediction 6: *Farmland values will be lower in regions with extreme topography*.

Boundary demarcation and enforcement would increase in more rugged terrain, which lowers profit or farmland value per acre. The predicted effect of topography on farmland value per acre follows from equation 3.2, i.e. $r_t < 0$.

Prediction 7: *Farms with closer market access will have higher per acre farmland value*.

Distance to market place is predicted to have a negative effect on output and input prices. Prices of production inputs and outputs are negatively associated with geographical distance to market or port centers (Chomitz and Gray 1996; Mendelsohn 1994).

With the theoretical framework now specified, I empirically test these predictions. The next chapter does precisely this.

CHAPTER 4: EMPIRICAL FRAMEWORK AND ANALYSIS

In this chapter the theoretical predictions are tested against data from the Agricultural Census of California of 1860. I first describe the ideal data needed for a study of this nature and the data actually collected. This is followed by the empirical strategy adopted and an analysis of the empirical results.

4.1 EMPIRICAL DATA FOR TESTING PREDICTIONS

The parameters specified in the theoretical model need to be represented by empirical data. Ideally one should use data that perfectly characterizes the parameters. However, one does not always have access to ideal data and is constrained to use data that most closely represents the parameters.

The first parameter that I represent is the measure of economic performance-empirically represented by farmland value. Empirical data is available at the individual farm level in the form of farmland value, essentially a farmer-reported cash value of his or her farmland. The next parameter that needs to be represented is parcel boundary uncertainty. Ideally I should have information on the exact level of boundary uncertainty in terms of a percentage for each parcel of land. Empirically however what can be used is a binary variable indicating whether the farm lies in an RS or MB-demarcated region, with the latter assumed to have greater boundary uncertainty.

When studying how land values differ across two systems of land demarcation, one should ideally have the two systems adjacent to each other which facilitates a well controlled natural experiment. This study avoids the issue of endogeneity in land demarcation systems to a large extent because the RS system filled up the gaps where the ranchos did not lie. In the state of California the RS-demarcated regions did lie side-by-side with the MB-demarcated ranchos. In this thesis I choose regions that are covered by either the RS or MB demarcation systems; in a few cases was I able to choose geographically adjacent regions with the two demarcation systems.

Acreage of parcels or farms, which is the choice variable in theoretical profit maximization, is available at the individual parcel or farm level. Exogenous parameters, such as terrain ruggedness or topography and the fertility of the soil on which the parcel or farm lies, should be represented by data at the farm level. In order to get such disaggregated data, one requires highly detailed land feature maps that can quantify topography and soil fertility at the parcel or farm level. Essentially all data or information on the model parameters should be disaggregated at the parcel or farm level. For my empirical purposes however, some of the exogenous parameters are represented by data at more aggregate levels. This is clearly laid out in the next few sections.

4.1.1 DESCRIPTION OF STUDY AREAS

In chapter 2 the land demarcation history of the state under the three successive governments was described. Figure 2.5 showed the location of the Spanish/ Mexican Land Grants and the RS Grid System. To answer the research question I choose areas that are covered entirely by rancho land or the RS grid system.

The state of California is divided up into counties. In the 19th Century state counties were divided up into administrative townships, which in turn consisted of farms. The Agricultural Census of California collected farm level data at the township level for each of the counties. The 19th century US Census data does not indicate whether the townships were subdivided by the RS grid system or not. I thus used 19th century county maps that indicate the type of demarcation system in the townships (see figures A.4- A.9 in the Appendix).[6] Townships were then chosen that were entirely rancho land or demarcated by the RS grid system. Table 4.1 shows these townships, their land demarcation system, the counties in which they lie and the number of sampled farms in each township. A random sample of 1 out of every 5 farms from each of the townships was chosen from the Agricultural Census data sheets- i.e. a sampling rate of 20% of farms.

TABLE 4.1: RS AND MB TOWNSHIPS STUDIED

County	Township	Demarcation system	Number of farms in sample
Alameda	Alameda	MB	12
	Brooklyn	MB	48
	Washington	MB	69
Santa Clara	Redwood	RS	12
	Santa Clara	MB	34
Solano	Benicia	MB	7
	Vallejo	RS	18
Sonoma	Analy	MB	46
	Sonoma	MB	10
	Vallejo	MB	17
	Washington	MB	33
Yolo	Washington	RS	25
	Merritt	RS	39
Fresno	Township 1	RS	17
Sutter	Nicolaus	RS	14
Marin	San Antonio	MB	15

Source: Rumsey (2003) and US Ag Census (1860).

Figure 4.1 below shows the geographical location of the townships. Note that these townships are located in central California near the coast and the Central Valley region. The right hand side panel shows a magnified image the townships demarcated by MB (shaded yellow) and by RS (shaded orange).

[6] These are old county maps that I digitized and geo-referenced the township boundaries onto a modern day county map of California using Arc-GIS software.

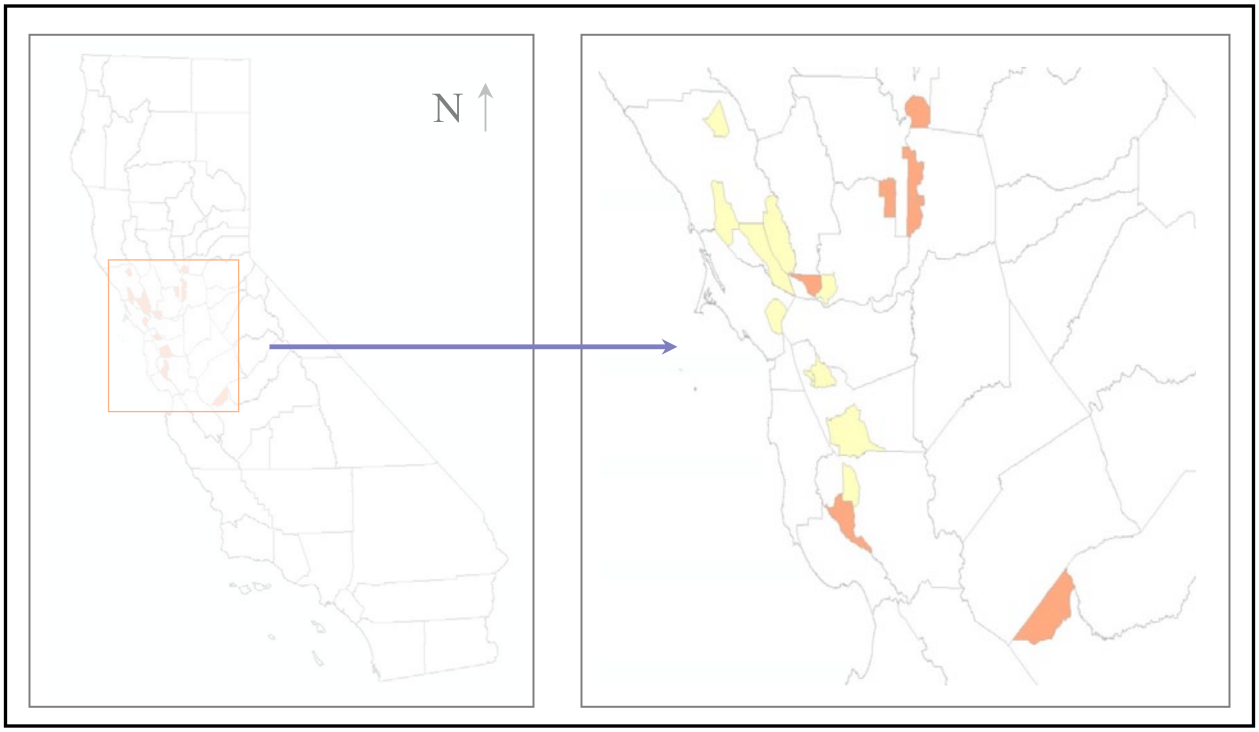

FIGURE 4.1: MAP OF CALIFORNIA WITH THE CHOSEN TOWNSHIPS HIGHLIGHTED.
Source: USGS (1970) and Rumsey (2003).

4.1.2 DESCRIPTION OF VARIABLES

Having laid out the history of land demarcation systems in the state of California, I choose the year 1860 for analysis. The RS system was implemented from the early 1850s onwards and started to spread out across the state. The patenting process of the Ranchos had begun under the California Land Act during the 1850s. During this period boundary uncertainty was widespread by virtue of the fact that rancho boundaries were demarcated using the MB. This natural experiment setting allows me to observe the differential effects of the two demarcation systems on my variables of interest.

I control for other variables that may exogenously affect farmland value. These include topography of the land, market access, soil quality, land use variables and population characteristics. For the soil quality information I use the California Department of Conservation FMMP program's data for generating average measures of land quality at the township-level.[7] Figure A.3 in the Appendix shows the mapping of farmland quality carried out by the FMMP program. To quantify topography of the land I derived averages of the percentage change in slope of the land for each township. Figure A.1 and A.2 in the Appendix show the Digital Elevation Models (DEM) used to arrive at these measures.

Citing the literature which states that distance to markets affects production input and output prices (Chomitz and Gray 1996), market access variables are derived at the township level. This is a measure of the linear distance from the center of a township to the county seat and applies to all farms within that township. Land use variables are data at the farm level indicating the quantity of various crops grown on the soil, market value of livestock and other produce from the farm. Population data was collected from the 1860 US General Census of Population on characteristics of the population, such as proportion of native and foreign-born populations and percentages of white and non-white races. A detailed definition of all variables is given in the Appendix.

Two important issues are addressed while answering my research question. One is the aspect of the rectangular grid system's effect on farmland value. The other is the uncertainty on land title that was prevalent in California at the time. As mentioned in Chapter 2 the patenting process of the Land Commission took several years to complete and thus what resulted was uncertain land title in several of the Ranchos. In order to

[7] Source: http://www.conservation.ca.gov/dlrp/FMMP/Pages/Index.aspx. These data are from the year 2002. While admittedly soil quality would be markedly different from the 1860 level because of developments in irrigation, I could find no usable source of data for soil quality in the 19th Century in order to quantify this variable at the township level. Arc GIS software was used generated topographical at the township-level.

represent the land title uncertainty during the 19th century, I include a proxy variable indicating the number of acres that were not patented by the US Land Commission by the year 1860. Table 4.2 gives the summary statistics of the entire sample of 427 farms within the 16 Townships.

This is followed by Table 4.3 which categorizes the summary statistics by MB and RS regions. Note the values that the central variable of interest takes i.e. Farmland value per acre. [8] Testing for difference of means, I find that the mean value in RS farms exceeds that of MB farms by $30 per acre, and this is statistically significant at the 95% confidence level. This supports the thesis that per acre farmland values are higher in RS farms. Considering other variables I find not much difference between RS and MB farms in Farmland category. MB farms are seen to be slightly more rugged than RS farms on average, which is because as per figure 4.1 MB farms lie towards the coast in my sample whereas RS farms lie mostly in the Central Valley region, the latter being associated with relatively flatter land. Market access variables indicate some differences between the RS and MB farms by virtue of geographical location of townships from county seats and San Francisco. Population characteristics are seen to be not very different between RS and MB farms.

In the next section I describe the empirical strategy used to test the predictions made in chapter 3.

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[8] As defined in the Data Appendix, Farmland value per acre is calculated as present cash value of a farm and added to this is the machinery and implement value. One argument can be made that implement value represents a measure of investment in the farmland and hence its inclusion is justified. However, a counter argument can also be made that implements need not differ significantly across farms with different systems of demarcation. The summary statistics of the variable farmland value per acre, both with and without implement value, is shown in the Data Appendix. The numbers indicate that the two variable specifications are very close to each other in magnitude and the correlation between then is close to one hundred percent. Hence the numbers suggest that there is no difference whether implement value per acre is added to farmland value per acre or not.

TABLE 4.2: SUMMARY STATISTICS- FULL SAMPLE (N = 427)

Variable Type and Name	Definition	Mean	Median	Min	Max	Std Dev
Dependent variable						
FARMLAND VALUE PER ACRE	Present cash value of farmland per acre	26	16	0	1,007	57
Farm acreage						
IMPROVED	Improved acres of farmland	234	120	0	5,000	455
UNIMPROVED	Unimproved acres of farmland	178	0	0	20,000	1,051
Land characteristics						
FARMLAND QUALITY	Farmland category (1-8 in increasing fertility)	4	4	2	8	2
PERCENT SLOPE	Township topography (av. % rise in slope)	7.77	8.70	1.08	22.62	5.58
Market access						
MARKET DISTANCE	Distance (miles) to County seat from township center	17.77	15.70	3.44	61.43	11.99
SFO DISTANCE	Distance (miles) to San Francisco from township center	43.81	37.51	10.10	115.48	25.30
COUNTY POPULATION	County population in 1860	8770	8927	3334	11912	3002
Land title security proxy						
UNPATENTED ACRES	Rancho acres in township not patented by 1860	17,039	10,610	0	88,675	20,027
Population ethnicity						
% NATIVE BORN	Percent native population in county	0.736	0.719	0.593	0.868	0.107
% WHITE POPULATION	Percent white population in county	0.943	0.976	0.217	0.993	0.149

Sources: See Data Appendix

TABLE 4.3: COMPARISON OF RS (N=128) & MB (N=299) SAMPLES

Variable name	Mean			Min		Max	
	RS	MB	Diff (MB-RS): t-value	RS	MB	RS	MB
	47	17	-3.46*	6	0	1,007	128
FARMLAND VALUE PER ACRE							
IMPROVED	202	247	0.99	2	0	4,000	5,000
UNIMPROVED	65	225	2.20*	0	0	562	20,000
	6	4	-12.06*	3	2	8	6
FARMLAND QUALITY							
PERCENT SLOPE	4.21	9.26	8.09*	1.08	1.59	22.62	17.19
MARKET DISTANCE	24.19	15.08	-6.22*	11.02	3.44	61.43	27.35
SFO DISTANCE	67.80	33.77	-13.66*	25.93	10.10	115.48	71.09
COUNTY POPULATION	5647	10078	18.13*	3390	3334	11912	11912
UNPATENTED ACRES	0	24,171	21.06*	0	0	0	88,675
% NATIVE BORN	0.795	0.712	-10.29*	0.706	0.593	0.868	0.847
% WHITE POPULATION	0.886	0.966	3.42*	0.217	0.929	0.993	0.989

* Indicates that the mean difference is statistically significant at the 5% error level.
Sources: See Data Appendix

4.2 EMPIRICAL STRATEGY AND ESTIMATES

In order to test the predictions I begin with a simple difference of means test for the variables of interest and compare the averages across townships demarcated by the two systems. Doing this allows me to observe facts as they appear on the ground. I then undertake an econometric analysis that allows me to control for other factors that may affect the observed differences in values. I use an OLS regression estimation technique where the dependent variable (y_i) is regressed on the binary demarcation parameter (RS_i)[9] with regression coefficient δ, a set of explanatory variables (X_i) with the regression coefficient vector (β) and an error term (u_i). This is specified as equation (4.1).

$$y_i = RS_i.\delta + X_i.\beta + u_i \quad (4.1)$$

A semi-log model is also estimated where the dependent variable y_i is transformed using a natural logarithm and is regressed on the set of independent variables. In a semi-log model the regression coefficients are mathematically interpreted as showing the percentage change in the dependent variable for a unit change in the independent variable.

To test for the prediction 1 I first regress only the RS binary variable on per acre farmland value, which is the dependent variable. The estimates are given in Table 4.4 under column 1. The δ coefficient of the RS variable is $30 per acre and it is statistically significant. This indicates that on average farmland in RS regions have higher per acre value than farms in MB regions- to the tune of $30 per acre of farmland. Using the same set of regressors in the semi-log model the δ coefficient on the RS binary is estimated as 1.10 and is statistically significant (column 1 of Table 4.5).[10]

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[9] RS = 0 indicates farm lying in township with all rancho land and RS = 1 indicates farm lying in township demarcated entirely by the rectangular grid.

[10] The R-square value of the semi-log model is higher than that of the previous model indicating a better model fit.

TABLE 4.4: PARAMETER ESTIMATES FROM OLS REGRESSION MODELS
DEPENDENT VARIABLE: FARM VALUE PER ACRE; FULL SAMPLE

VARIABLE	**1**	**2**	**3**	**4**	**5**	**6**
INTERCEPT	16.89	23.49	25.50	33.00	74.85	43.37
	(1.06)*	(3.05)*	(4.69)*	(4.43)*	(7.28)*	(8.01)*
Demarcation						
RS	30.50	26.90	30.29	26.57	26.39	34.73
	(8.77)*	(7.55)*	(6.67)*	(5.55)*	(4.85)*	(13.36)*
Land features						
PERCENT SLOPE		-0.71	-0.68	-0.36	-0.30	
		(0.301)*	(0.23)*	(0.23)*	(0.25)	
FARMLAND QUALITY			0.64	1.30		
			(2.44)	(2.30)		
RS*(PERCENT SLOPE)						-1.38
						(0.68)*
Land title uncertainty						
UNPATENTED RATIO				-4.80	-3.87	
				(3.60)*	(3.59)	
Market access						
MARKET DISTANCE				-1.33	-1.08	-1.28
				(0.43)*	(0.29)*	(0.29)*
$(\text{MARKET DISTANCE})^2$				0.017	0.014	0.015
				(0.007)*	(0.007)*	(0.007)*
COUNTY POPULATION					-0.0014	-0.0012
					(0.001)*	(0.0006)*
SFO DISTANCE			-0.13			
			(0.15)			
Population						
% NATIVE BORN					-37.76	
					(17.35)*	
Observations	427	427	427	427	427	427
F value (d.f.)	26.89* (426)	14.38* (426)	7.32* (426)	5.32* (426)	5.20* (426)	7.43* (426)
R^2	0.059	0.063	0.064	0.070	0.079	0.081

* Indicates statistical significance at 10% error level with one-tailed t-test. Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.

TABLE 4.5: PARAMETER ESTIMATES FROM OLS REGRESSION MODELS
DEPENDENT VARIABLE: LN (FARM VALUE PER ACRE); FULL SAMPLE

VARIABLE	**1**	**2**	**3**	**4**	**5**	**6**
INTERCEPT	2.31 (0.063)*	2.41 (0.102)*	2.76 (0.14)*	2.67 (0.16)*	2.90 (0.25)*	5.33 (0.39)*
Demarcation						
RS	1.10 (0.091)*	1.04 (0.097)*	1.40 (0.11)*	1.15 (0.098)*	1.009 (0.16)*	1.45 (0.18)*
Land features						
PERCENT SLOPE		-0.010 (0.008)	-0.010 (0.008)	-0.002 (0.008)	-0.004 (0.009)	-0.02 (0.011)*
Land title uncertainty						
UNPATENTED RATIO					-0.26 (0.23)	-0.18 (0.216)
Market access						
MARKET DISTANCE				-0.032 (0.012)*	-0.037 (0.012)*	-0.028 (0.012)*
$(\text{MARKET DISTANCE})^2$				0.0004 (0.0002)*	0.0005 (0.0002)*	0.0005 (0.0002)*
COUNTY POPULATION						0.00004 (0.00003)*
SFO DISTANCE			-0.01 (0.002)*			
Population						
% NATIVE BORN						-4.08 (0.55)*
Observations	427	427	427	427	427	427
F value (d.f.)	104.79* (426)	53.03 * (426)	43.07* (426)	28.80* (426)	23.34* (426)	28.43* (426)
R^2	0.197	0.200	0.234	0.214	0.217	0.322

* Indicates statistical significance at 10% error level with one-tailed t-test. Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.

The control variables are now added to the regression models. The regression estimates for testing prediction 6 are shown in columns 2 and 3 of Table 4.4. The estimates indicate that per acre farmland value declines by approximately \$0.70 for a unit increase in the percentage slope. The sign of the parameter is negative and statistically significant in the specifications given under columns 2 and 3. The estimates from the semi-log model are given under columns 2 and 3 of Table 4.5. They indicate that the percentage decrease in farmland value per acre for a unit increase in percent slope is 0.01%, although not statistically significant.

The estimates of the regression model testing for prediction 5 are given under columns 3 and 4 of Table 4.4. The parameter estimates show an expected positive sign. But in terms of statistical significance there is none. More rugged terrain is negatively correlated with the soil quality of the farmland in the dataset[11]; the farmland quality variable is dropped in the next two regression models.

To test prediction 7 I include various measures of market access in the regression models. The port of San Francisco was a major trading port in the 19th Century. Distance to this city from townships is included as one measure of market access. In Table 4.4 the results of the regression model controlling for the distance to the major trading port of San Francisco are shown under column 3. This coefficient takes the expected negative sign but it is not statistically significant. Column 3 of Table 4.5 shows the parameter estimate for this market access measure as -0.01 and statistically significant.

Another measure of market access I use is the geographical distance to County seat from each of the Townships. Column 4 and 5 of Tables 4.4 show the results of regression models controlling for this measure of market access. The sign of the market distance variable takes the expected negative sign and is statistically significant in both models. I check for the non-linear relationship of distance and farmland value by including a squared distance measure. This term

[11] The correlation coefficient is -0.34.

assumes a positive sign indicating that the negative effect of the linear distance term decreases as distance grows. Other control variables are accounted for in the regression models. These are the county population and the percentage of native born population in the county. The estimates are given under columns 5 and 6 respectively in tables 4.4 and 4.5.

In the semi-log specification model this results of this prediction are given in columns 4, 5 and 6 of Table 4.5. In this model the result is the same in terms of the parameter signs and statistical significance. They indicate that farmland value per acre decreases by approximately 3% for a unit (mile) increase in distance to the County seat.

I include another measure of land title uncertainty which takes into consideration the uncertainty surrounding the patenting process of the ranchos up to 1860. The Board of Land Commissioners' patenting process took several years and this left many Rancho owners uncertain about their title to land. I use the variable Unpatented Ratio which is a ratio of the unpatented acres of rancho land by 1860 to total rancho land in a Township. Columns 4 and 5 of Table 4.4 show the parameter estimates as negative but significant in only one model. In the semi-log model specification the estimates are shown in columns 5 and 6 of Table 4.5. Again the estimates are negative but neither of them is statistically significant.[12]

To test prediction 4 an interaction term between the RS binary and township topography is added to the estimating equation.[13] Column 6 of Table 4.4 shows the estimates of farmland value per acre as the dependent variable using the specification of equation (4.1). The RS parameter estimate shows the predicted sign. The parameter estimate of the interaction term is negative as predicted and also statistically significant. This estimate indicates a $1.38 decrease in Farmland value per acre for a unit increase in percent slope for farms in RS townships.

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[12] This is possibly due to the inability to calculate this ratio with accuracy using GIS software since the old township maps I used did not have the boundaries of the Ranchos clearly demarcated.
[13] Thus the higher a value this interaction term assumes, the more rugged the terrain upon which RS is used.

4.2.1 Testing farmland investment incentives

Table 4.6 provides the difference of means test results of prediction 2. It is shown that the mean percentage of unimproved acres in MB farms as 32% as opposed to 21% in RS farms. This mean difference is statistically significant at the 1% error level. Table 4.7 shows the results of a model where the dependent variable is Unimproved Acres as a Proportion of Total Farmland Acres. The formulation of this regression model is that given by equation (4.1). I estimate a simple model with the RS variable and control for ruggedness of terrain. The sign of the RS coefficient is negative as predicted and statistically significant. This estimate indicates that RS farms have approximately 9% lower unimproved farm acreage. The sign of the terrain slope coefficient is positive, which indicates that in more rugged terrain one observes that farmland owners would have greater proportions of their land unimproved, independent of whether or not they were RS farms or not.

Table 4.6: Difference of Means Test
Variable: Fraction of Unimproved acres of farmland

Demarcation	Number of farms	Mean	Std Dev	Min	Max
MB	301	0.32	0.38	0	1.00
RS	126	0.21	0.32	0	0.99

Mean difference = 10.94%
t-value (assuming unequal variance across groups) = 2.99 (significant at 5% error level).

TABLE 4.7: REGRESSION ESTIMATES
DEPENDENT VARIABLE: FRACTION OF UNIMPROVED FARMLAND ACRES

VARIABLE	**Estimates**
INTERCEPT	0.28
	(0.037)*
Demarcation:	
RS	-0.090
	(0.039)*
Land features:	
PERCENT SLOPE	0.00381
	(0.003)
F value (d.f.)	4.50* (426)
R^2	0.021

* Indicates statistical significance at 10% error level with one-tailed t-test. Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.

4.2.2 TESTING UNIFORMITY OF FARMSIZE DISTRIBUTION

Table 4.8 provides the difference of means test results of prediction 3. The mean size in of the MB farms is 472 acres as opposed to 266 acres in RS farms as seen in. Also note how the extremes differ in the two demarcation systems. The largest farm size in MB regions is greater than 20,000 acres. I also test this prediction with a simple regression model following the specification of equation (4.1). The dependent variable is Total Farm Acres and the independent variable is the RS binary with a control for terrain ruggedness. The magnitude of the RS coefficient is about the same as the mean difference and it is also negative and statistically significant.

TABLE 4.8: DIFFERENCE OF MEANS TEST
VARIABLE: TOTAL ACRES OF FARMLAND

Demarcation	**Number of farms**	**Mean**	**Std Dev**	**Min**	**Max**
MB	301	472	1327	20	20,200
RS	126	266	421	3	4000

Mean difference = 206 Acres
t-value (assuming unequal variance across groups) = 2.42 (significant at 5% error level).

TABLE 4.9: REGRESSION ESTIMATES
DEPENDENT VARIABLE: TOTAL ACRES OF FARMLAND

VARIABLE	Estimates
INTERCEPT	485
	(82.95)*
Demarcation:	
RS	-212
	(84.82)*
Land features:	
PERCENT SLOPE	-1.33
	(5.62)
F value (d.f.)	1.46 (426)
R^2	0.007

* Indicates statistical significance at 10% error level with one-tailed t-test.
Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.

4.3 ADJACENT RS-MB TOWNSHIPS SUB-SAMPLES

I further study RS and MB Townships that are geographically adjacent to each other. Two sets of adjacent townships in Solano and Santa Clara counties are used. In this sample the sets of RS -- MB adjacent Townships are: Vallejo -- Benicia in Solano County and Redwood -- Santa Clara in Santa Clara County. In figure 4.2 below the Solano County townships are circled as 1 and the Santa Clara County townships are circled as 2.

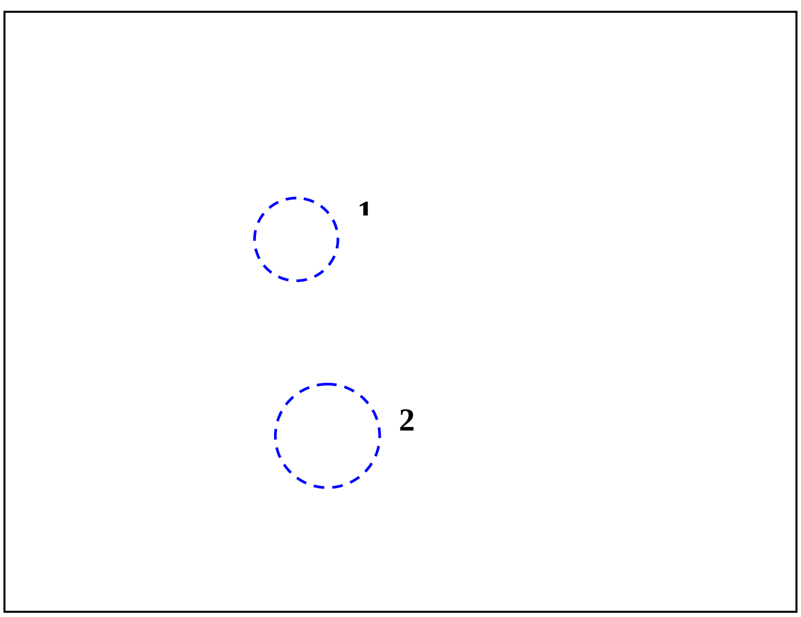

FIGURE 4.2: ADJACENT RS AND MB TOWNSHIPS FOR CASE STUDIES.

Table 4.10 provides summary statistics of this sub-sample of farms by land demarcation system. Although this sample size is too small to draw general conclusions, it is still interesting to note the results of some of the theoretical predictions. Unimproved acres are higher in MB farms of Santa Clara County. There are some differences seen in the topography of the adjacent townships. Not much difference is seen in the farmland categories though. I find that in Solano County, the RS farms average $33 as opposed to $14 in the MB farms and this difference is statistically significant at the 5% error level. In the Santa Clara set of adjacent townships, the mean value for RS farms is $21 as opposed to $14 for the MB farms and this difference is also statistically significant at the 5% error level.

TABLE 4.10: COMPARISON OF RS & MB MEANS: ADJACENT TOWNSHIPS SUB-SAMPLE

Variable name	Solano County		Santa Clara County	
	RS (n=18)	MB (n=7)	RS (n=13)	MB (n=34)
FARMLAND VALUE PER ACRE	33.02	14.24	21.36	13.79
UNIMPROVED	0	0	100	316
FARMLAND QUALITY	2.54	4.12	2.75	2.24
PERCENT SLOPE	5.06	10.62	22.62	1.59
MARKET DISTANCE	17.23	12.09	11.01	5.04
SACRAMENTO DISTANCE	51.53	47.82	97.52	89.23
UNPATENTED ACRES	0	0	0	26,891

* Indicates that the mean difference is statistically significant at the 5% error level.
Sources: See Data Appendix

I estimate the specification of equation (4.1) using OLS with farmland value per acre as the dependent variable. The results provided in Table 4.11 indicate that the coefficient of RS is positive and significant in Solano County, while controlling for farmland quality. The RS coefficient in Santa Clara County is positive as predicted while controlling for farmland quality. However it is not statistically significant. The coefficient of the variable farmland quality takes the predicted positive sign in both specifications.

TABLE 4.11: PARAMETER ESTIMATES FROM OLS REGRESSION MODELS
DEPENDENT VARIABLE: LN (FARM AND IMPLEMENT VALUE PER ACRE)

VARIABLE	Solano County	Santa Clara County
Demarcation:		
RS	1.85	0.11
	(0.12)*	(0.22)
Land features:		
FARMLAND QUALITY	0.62	1.048
	(0.035)*	(0.07)*
F value (d.f.)	878* (24)	220* (46)
R^2	0.987	0.907

* Indicates statistical significance at 10% error level with one-tailed t-test.
Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.

This chapter has laid out the empirical results following the predictions of the theoretical model. In the concluding chapter I summarize these results and outline the future research agenda.

CHAPTER 5: CONCLUSION

In this thesis I have examined the effects of land demarcation systems on economic performance in nineteenth century California. Farmland values per acre and incentive to invest in farmland improvements are used as measures of economic performance. The setting and history of the state of California provided me with a natural experiment in order to answer the research question. The results of Chapter 4 have answered the central research question to a large extent. The prediction made by Libecap and Lueck (2009b) that land markets function more efficiently in RS regions because of the ability of land parcels to be reorganized based on changing land market conditions, and that landowners in RS regions have the advantage of network effects, are corroborated by my results.

Farmland value per acre is seen to be higher in RS regions as compared to the MB regions with the difference being statistically significant. The parameter estimates are seen to be robust with little fluctuation in their values even after adding in controls for exogenous factors that have an effect on farmland value. More rugged topography increases boundary demarcation and enforcement costs as argued by Libecap and Lueck (2009b). My results supported this prediction as well with land slope's observed negative effect on farmland value. Also observed was that the RS grid system is costly to impose in more rugged terrain.

The literature on how market access affects production input prices is also corroborated by my results. Market access is seen to be a significant determinant of farmland value; this holds for both variables- township distance to county seat and distance to San Francisco. Distance to county seat reduces farmland value per acre by approximately 0.03% for each unit distance (mile).

Boundary uncertainty in the MB farms is seen to negatively affect the proportion of farmland that is improved by the farmland owners. Individualistic land demarcation by farmland owners thus leads to lowered incentive to invest in farmland improvement as opposed to the centralized rectangular demarcation system. Farmland value is negatively affected by title uncertainty as seen by the measure of rancho acres not patented. However, a general conclusion cannot be drawn from this result because of the parameter estimate's statistical insignificance.

Individualistic demarcation under MB leads to a lack of uniformity in the size distribution of the land as seen by the results. RS creates more efficient land market conditions by virtue of its more uniform land size distribution. This allows land parcels to be more easily reorganized when market conditions change.

In my adjacent townships sub-samples, the predictions largely hold true. This is interesting to note despite the restriction of small sample size. In future research I would have to locate more such adjacent townships and thereby increase the sample size. From this I would be able to draw much stronger conclusions about the theoretical predictions.

Given my results of how farmland values in MB regions are negatively affected as compared to RS regions, I ask myself whether this is enough evidence to draw a general conclusion about California, or even about the issue in general. This study of faced a dearth of data availability in terms of limited choice of administrative townships with only one of the two land demarcation systems in place to allow me to choose random samples. What is exciting is that this research is new for the state of California. However, more research is required in this area for different states within the US and also different countries of the world.

It is interesting to note that the MB system still prevails in the old rancho areas of California and many parts of the world. Organized systems of land demarcation have emerged, but they are largely restricted to small pockets and little coordination between adjacent demarcation systems. It may that it is infeasible to convert to the RS system in these areas. The short term costs of converting the landscape may be covered by potential long-term gains of efficient land markets.

Another question that requires further research is trying to answer if rectangles are really the most efficient land parcel shapes. Amongst the early attempts at justifying rectangular farm shapes is that of Carlton Barnes. Barnes (1935) compares the cost of providing various public services and farm operations in square and rectangular farms. Under the RS system he writes about the long-lot division of farms designed essentially to provide river frontage to a maximum number of farms, or equivalently, making a given length of road serve a maximum number of farms. He concludes that farm machine operations are more efficient in long rectangular fields as opposed to square ones.[14] Lee and Sallee (1974) provide a theory of farm shape by considering farming operations. They take Barnes' work forward by providing a formal model to justify rectangular farms over square ones and arrive at an optimal length-breadth ratio of 1.23:1.

Land is demarcated into various geometrical patterns and shapes when settlement occurs. Theories have been offered on which shapes enable the most efficient use of the land. The form and location of farms on a homogenous plain was addressed by the German economist August Losch. Losch (1954) concluded that the shape of farms would be hexagons packed together on the plain with hexagonal central market places. Lee and Sallee (1974) note that Losch arrives at this conclusion not on the basis of efficient farming operation, but rather theorizing on optimal location of farms in order to minimize distance from farmstead to central market place.

While theories on farm field shapes are existent, it is important for economists to step in and contribute to this important literature. Studies of this nature in different parts of the world are an exciting research agenda.

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[14] Working longitudinally there is less time spent in turning the machines at the other end of a rectangular field as opposed to a square field.

Appendix

Data Sampling

California data from the 1860 Census of Agriculture was manually entered into excel from microfilm copies of the original records. Townships completely covered by Rancho land or the Rectangular Survey grid system were sampled. Table 4.1 shows the Townships that were sampled. The 1860 Census was sampled at a 20% rate.

Farm Acreage and Improvement

In the 1860 US Census of Agriculture land is considered "improved" if it has been cleared and utilized for grazing or crop production (or which was fallow at the time of the enumeration) and is "unimproved" otherwise. To find the total acreage of the farm I calculate:

Total Acres= (Improved Acres + Unimproved Acres)

I also calculate the proportion of farmland that is unimproved as:

Percent Unimproved = Unimproved Acres/ Total Acres

Farmland Value

The U.S. Census of Agriculture collects specific valuation information from farmers including: present cash value of farmland and value of farming implements and machinery reported in dollars. Using this data I calculate Farmland value per acre as:

Farmland value per acre = (Present cash value of farmland + Value of farming implements and machinery)/ (Total Acres)

Variable specification	Sample size	Mean	Stdev	Min	Max
Farm value per acre (with implement value)	427	25.89	57.09	0.09	1007
Farm value per acre (without implement value)	427	24.45	56.10	0.06	1000

Pearson Correlation Coefficients
N = 427; Prob > |r| under H0: Rho=0

	Farm value per acre (with implement value)	Farm value per acre (without implement value)
Farm value per acre (with implement value)	1.00	0.997 < .0001
Farm value per acre (without implement value)	0.997 < .0001	1.00

Percent Slope variable

To measure the topography of the land or its ruggedness, I used Arc-GIS software to calculate the Percent Change in Slope of the Land. I used Arc-GIS to calculate an average of this measure for each of the Townships in my data set. This is measured as a simple percentage number i.e. the higher the number, the more percentage change in slope, and thus the more rugged the terrain in a Township. Figures A.1 and A.2 show the Digital Elevation Model (DEM) used in Arc-GIS. These DEM maps were made available from the US Geological Survey website.

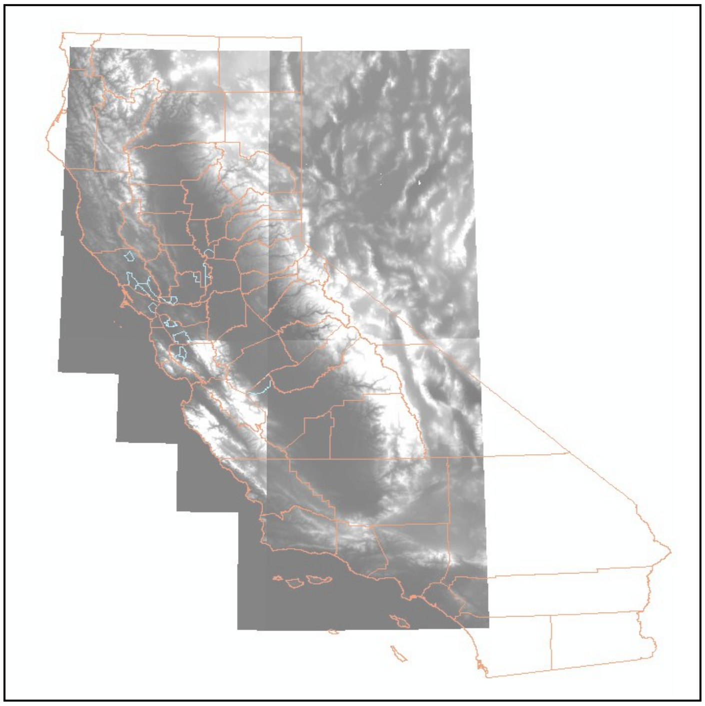

FIGURE A.1: Digital Elevation Model (DEM) of California used to derive topographical information; dark shade indicates low lying areas and white shade indicates higher or mountainous terrain; Source: http://www.usgs.gov/state/state.asp?State=CA.

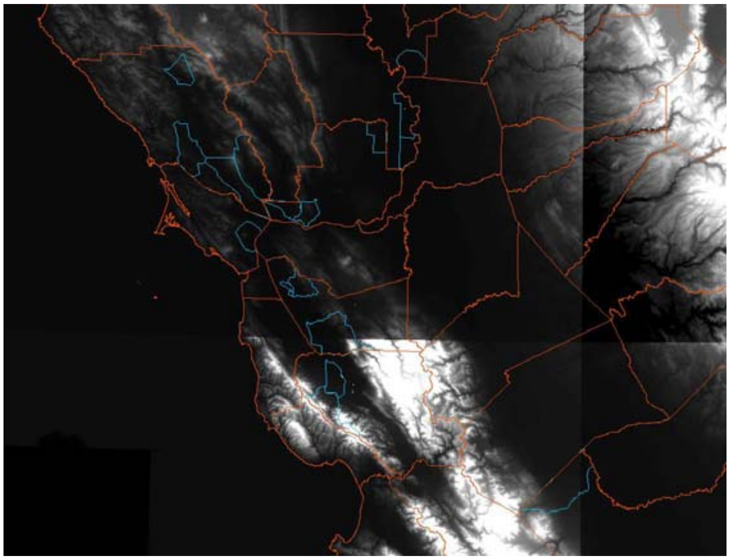

FIGURE A.2: Study areas (Townships in blue outline) geo-referenced with the DEM.

Farmland Quality Variable

Farmland Quality was measured as the average of soil quality types in a Township. Each type of soil quality was given a number according to the classification of the California Department of Conservation's Farmland Mapping and Monitoring Program (FMMP). Nine types of farmland are shown in figure A.3. The number 9 was assigned to Prime farmland and in decreasing order up to the number 1 for Other land. Thus 9 represents the best quality farmland and 1 represents the worst quality farmland. One qualifier is that this data is from 2002. I could use only this because I could not locate 19^{th} century soil quality maps that I could use in order to calculate average measures at the Township level.

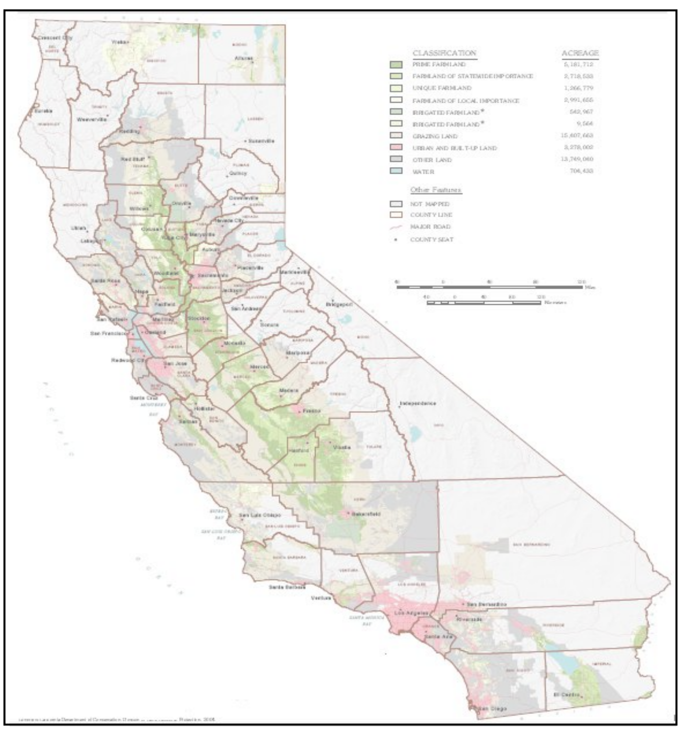

FIGURE A.3: Mapping of California's farmland quality by the FMMP program.
Source: http://www.conservation.ca.gov/dlrp/FMMP/Pages/Index.aspx

Distance to Geographical Point Vectors (County seats and San Francisco)

A map of California counties and county seats prepared by the US Geological Survey was used to determine geographical locations of the county seats and the city of San Francisco. Locations were digitized into point data using Arc-GIS software. In the analysis, Market Distance is the straight-line distance measured in miles between the centroid of a Township and the seat of the County to which it belongs. Distance to San Francisco is the straight-line distance measured in miles between the centroid of a Township and the point representing San Francisco.

Land Title Uncertainty variable

To capture the uncertainty pertaining to the Patenting process of the Board oc Commissioners of the 1851 Land Commission, I constructed a Land Title Uncertainty variable. This is the Ratio of un-patented acres of rancho land in townships. For this I used the old Township maps and noted the ranchos lying within each township and their acreage as given by Beck and Haase (1974). Cowan (1956) gives details of the Ranchos, including their acreage and the year of patenting or rejection by the Board of Land Commissioners. The variable is thus constructed as-

Not Patented Ratio= (Un-patented acres of rancho land in the Township by the year 1860)/ Total area of Rancho land within the Township

County maps showing 19th Century Townships and Ranchos

Figures A.4- A.9 show the county maps I used to collect my sample of Townships that were either completely Rancho land or completely covered by the Rectangular Survey grid system.

FIGURE A. 4: Alameda County map showing administrative township boundaries, ranchos and rectangular system's grid

Source: Rumsey (2003)

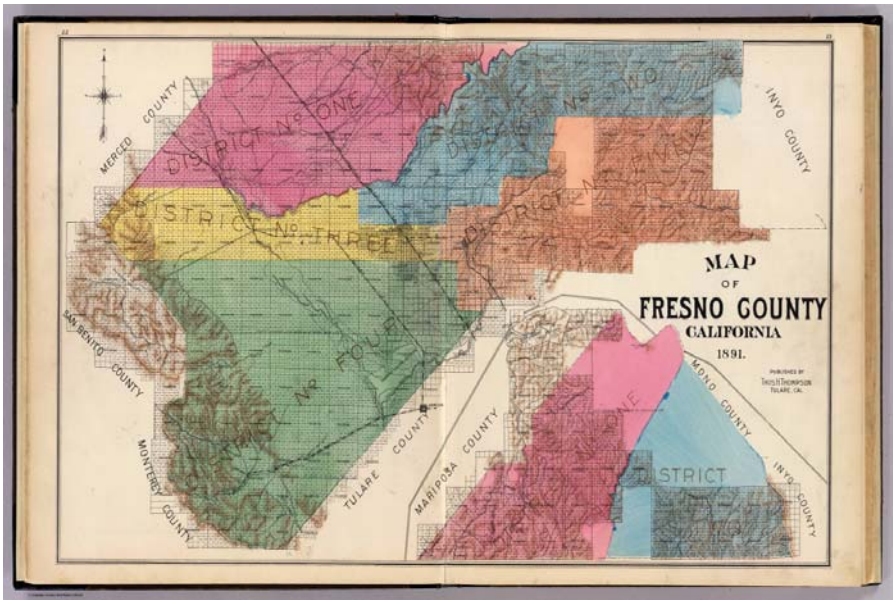

FIGURE A.5: Fresno County map showing administrative township boundaries, ranchos and rectangular system's grid
Source: Rumsey (2003)

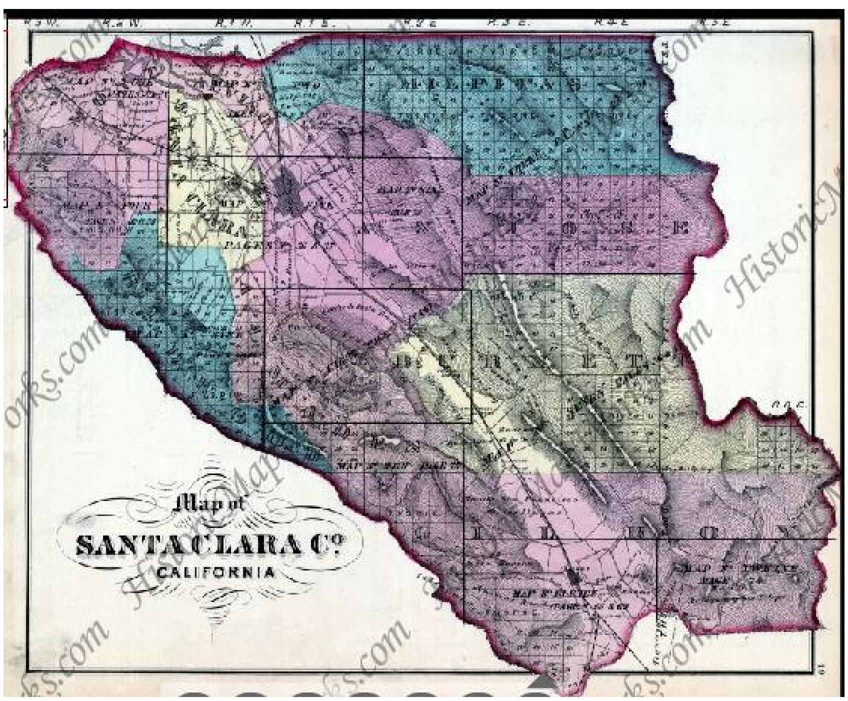

FIGURE A.6: Santa Clara County map showing administrative township boundaries, ranchos and rectangular system's grid
Source: Rumsey (2003)

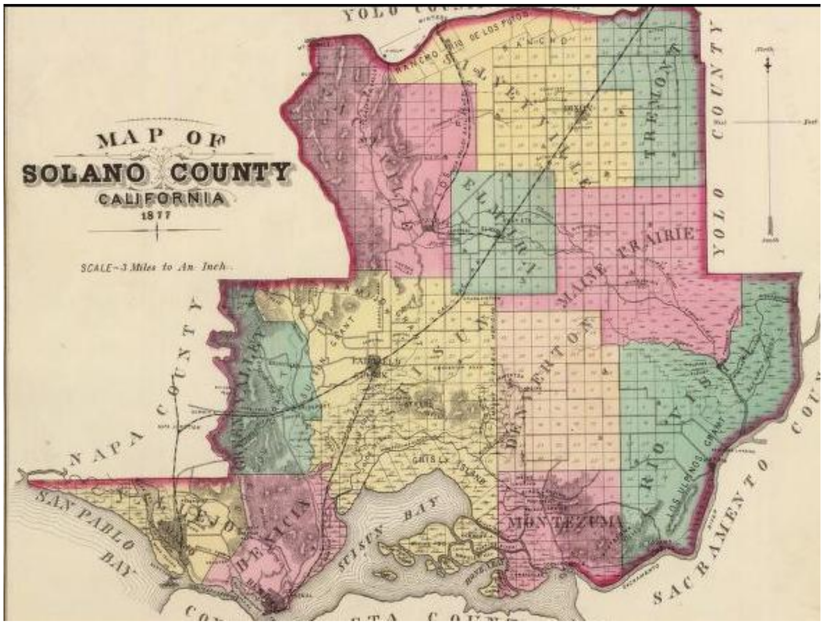

FIGURE A.7: Solano County map showing administrative township boundaries, ranchos and rectangular system's grid.
Source: Rumsey (2003)

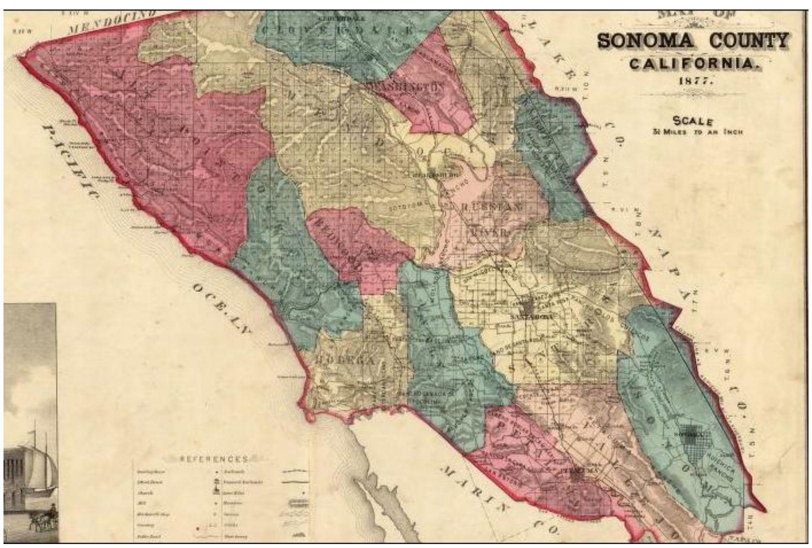

FIGURE A.8: Sonoma County map showing administrative township boundaries, ranchos and rectangular system's grid.
Source: Rumsey (2003)

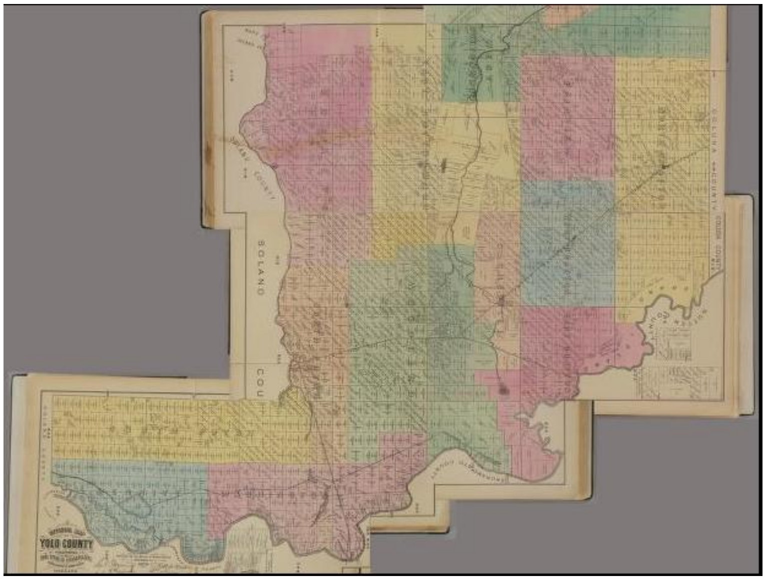

FIGURE A.9: Yolo County map showing administrative township boundaries, ranchos and rectangular system's grid.
Source: Rumsey (2003)

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