A LEGACY OF HISTORY: 19TH CENTURY LAND DEMARCATION AND AGRICULTURE IN CALIFORNIA

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ABSTRACT: This paper examines the economic effects of a natural experiment in land demarcation in 19th century California. Land demarcation occurs in two dominant forms: metes and bounds (MB) and the rectangular system (RS). In MB individuals claiming and specification of land parcels, while in the RS land is surveyed and demarcation prior to settlement and is organized in uniform grid of square plots. It is hypothesized that the RS reduces transactions costs and creates a coordinating network among participants in a land market, thereby leads to a more efficient land market. A land demarcation model predicts that RS areas have higher farmland values per acre and create more incentives to invest in the land. We use farm-level data from the 1860 Agricultural Census, for California regions where both MB and RS are found, to test these and related predictions. Preliminary evidence indicate that farmland values per acre are lower and there is less incentive to invest in the land in MB regions compared to RS regions.

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I. INTRODUCTION

The history of land has been an enduring topic among economists, historians, and political scientists. The most prominent issues have included the claiming and allocation of land, settlement of frontier lands, the structure of property rights and the reform of land ownership regimes. The literature is voluminous and still growing. The study of land demarcation, however, is not among this literature, even though land demarcation is fundamental to property law, land use and land markets (Libecap and Lueck 2011a). Land demarcation is one of the earliest actions of organized human groups. Territories to hunting and gathering sites have been marked and defended among the most primitive peoples (Bailey 1992). The earliest agricultural societies defined rights to plots of land for farming (Ellickson 1993). In modern societies rights are designated for residential and commercial use in dense urban areas, for farmland in highly mechanized large-scale fields, for landscapes allocated primarily as wildlife refuges or wilderness parks, and for such related resources as minerals and water. Demarcation defines property boundaries, parcel shapes and locations, and hence, is a foundation for land use and land markets.

Two land demarcation regimes have dominated historically: metes and bounds (MB) and the rectangular system (RS). MB is easily the most prevalent and is found in parts of every continent for both agricultural and urban land. RS was used extensively by the ancient Romans, and is now found in large regions of the U.S., Canada, and Australia, as well as on a smaller scale in urban areas throughout the world (Libecap and Lueck 2011a; Libecap, Lueck, and O’Grady 2011).

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1 We use the English term ‘metes and bounds. ‘Metes’ refer to a boundary defined by direction and distance between terminal points, while ‘bounds refer to local boundary descriptions (Merrill and Smith xxxx).
In this paper we take advantage of a natural experiment in California to examine the effects of the two dominant land demarcation systems: metes and bounds (MB) and the rectangular system (RS). Under MB land is demarcated by local, natural features (trees, streams, rocks) and relatively permanent human structures (walls, bridges, monuments). Parcels are described independently by perimeter and linked to a specific survey within a local political jurisdiction. Individuals take little account of the spatial and temporal impacts of their choices. Demarcation is vague and imprecise (“four paces from the most northerly rock pile…”) and idiosyncratic. There are no uniform addresses, boundaries, shapes, sizes, or alignments. Under RS, however, plots are described by a geographically-based address that is part of a large, uniform grid of identical squares that define shape, size, and (directional) alignment. The placement of each parcel is communicated by this network, even to those remote from the site. Boundaries are positioned to avoid overlap and dispute and situated for the development of market roads along property lines.

The two systems can be usefully distinguished by their setup costs and their costs of continued use (Libecap and Lueck 2011b). MB has low initial setup costs, but fails to provide coordination among agents, implying that there will be relatively higher adjustment and transaction costs in the future. A centralized and coordinated RS, however, is a network that has higher upfront costs of implementation compared to MB because of systematic survey prior to occupancy. RS however, defines land ownership in a manner that reduces the subsequent costs of measurement, enforcement, location, and exchange of parcels.

Figure 1 is a satellite image showing where the two demarcation systems are adjacent to each other along the US - Mexico border in Yuma, AZ. The MB system is to the left (western) half and the RS system is adjacent to the right (east). The land is flat and fertile along the Lower Colorado River and the figure shows the distinction between the two systems clearly. The RS
area shows a coordinated network of square parcels, align long a north - south axis, while the MB area shows an uncoordinated mosaic of parcel, often rectilinear but not spatially coordinated or aligned.

Figure 1

Parcels are described differently under the two systems. Under MB parcels are described by their perimeter with reference to natural and often temporary. These features of the land are often only locally known and understood. For example, Hornbeck (1978) provides the following description of a large landholding called the Rancho San Andres in Santa Cruz County, California covering a total of 8,912 acres, noting

... 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 the RS system, parcels are demarcated using 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 2011a, 2011b). A typical parcel description would be “Section 8, Township 14 South, Range 13 East, Gila and Salt River Meridian.” This simple description gives a location in downtown Tucson, Arizona.

California history creates a natural experiment because the historical governing regimes of Spain, Mexico and the US used both MB and RS. Since the 1850s these regimes lie adjacent to each other throughout the state. The large land grants created under Spanish and Mexican rule were demarcated under MB, while the remaining lands were demarcated under RS after the Mexican-American War gave the US control of California. Because the ranchos were outside the
RS system they we subdivided internally using idiosyncratic MB surveys. This natural experiment allows us to study demarcation effects on economic performance.²

The imprecise and vague nature of MB, as opposed to the more systematic RS, will lead to a greater likelihood of property boundary disputes and this in turn is likely to lead to lowered incentives for the owners of such property to invest in it—thus lowering land value. Libecap and Lueck (2011b) find that RS lowers the costs of land development and exchange through its measurement, enforcement, and incentive effects as opposed to the MB. 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. In this study we pursue these and related forces in the California setting.

We begin in section II with a short history of land demarcation systems, focusing on the developments in the United States and California. In section III we develop a model to examine the differential effects of demarcation under both metes and bounds and the rectangular survey. Section IV is an empirical analysis of land demarcation and land markets using data from 19th century California where a natural experiment in demarcation allows econometric identification of these effects. Farmland values in 19th century California are our primary measure of economic performance. In Section V we summarize our findings and discuss the implications of our findings—and their striking modern persistence—for economic growth and its relationship to property institutions.

² A similar natural experiment occurred in Ohio and is exploited in Libecap and Lueck (2011b)
II. HISTORY OF LAND DEMARCATION IN CALIFORNIA

Most land in the world has been and is currently demarcated using indiscriminate or unsystematic systems like MB (Brown 1996, Estopinal 1993, Gates 1968, Hubbard 2009, Linklater 2002, McEntyre 1978, Price 1995, Thrower 1966). Aside from Ancient Rome no widespread use of RS occurred until the US began its system in 1785. In California land demarcation was established under three successive regimes (Morris 1994): Spain from the 1521 to 1821), Mexico from 1822 to1848), and the US from 1848 to the present. The system of metes and bounds was used by Spain and Mexico before the US introduced the rectangular system, which then was applied to all remaining US land within California. It is this history that presents a natural experiment for our study of land demarcation effects. Table 1 summarizes the key events and periods for land demarcation in California.

Table 1

A. Land Demarcation in the United States

Mete and bounds demarcation in the United States ended with the Land Ordinance of 1785 (Hubbard 2009). The law required that the federal public domain be surveyed prior to settlement and that it follow a rectangular system. Land sales were to be the primary source of revenue for the federal government, and the government bore the initial costs of survey to provide a uniform grid of property boundaries that were standard regardless of location and terrain. The RS applied to most of the U.S. west and north of the

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3 An extensive discussion is found in Libecap and Lueck (2011a). The term ‘metes and bounds’ is primarily an English term though we use it to describe an decentralized, topography-based demarcation system. Geographers (e.g., Thrower 1966) use the term ‘indiscriminant’ survey.

4 Text at http://memory.loc.gov/cgi-bin/query/r?ammem/bdsdcc:@field(DOCID+@lit(bdsdcc13201). It was replaced by the Land Ordinance of 1787, the Northwest Ordinance that allowed for larger individual allotments. Text at http://rs6.loc.gov/cgi-bin/ampage?collId=llsl&fileName=001/llsl001.db&recNum=173
Ohio River and west of the Mississippi north of Texas. Other nations also had a history of RS demarcation.\(^5\)

The American rectangular system uses a network of meridians, baselines, townships, and ranges to demarcate land.\(^6\) The survey begins with the establishment of an Initial Point with a precise latitude and longitude. A Principal Meridian (a true north-south line) and a Baseline (an east-west line perpendicular to the meridian) are referenced through the Initial Point. On each side of the Principal Meridian, land is divided into square units (six miles by six miles) called townships. A tier of townships running north and south is called a “range.” Each township is divided into 36 sections; each section is one mile square and contains 640 acres. These sections are numbered 1 to 36 beginning in the northeast corner of the Township.\(^7\) Each section can be subdivided into halves and quarters (or aliquot parts). Each quarter section (160 acres) is identified by a compass direction (NE, SE, SW and NW). Each township is identified by its relation to the Principal Meridian and Baseline.\(^8\) In this manner, properties are positioned relative to one another in a standardized way. Figure 2 shows the basic features of RS in the US.

**Figure 2**

There are 34 sets of Principal Meridians/Baselines—31 in the continental United States and 3 in Alaska. The rectangular system began with the first survey in eastern Ohio on the Pennsylvania border at what is now called the Point of Beginning (Hubbard 2009, Linklater

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\(^5\) The Romans actually extensively used a rectangular system called the centuria quadrata that was started in the 2\(^{nd}\) Century BC (Libecap and Lueck 2015). The Dutch also used rectangular systems in large drained areas. Both of these systems are still visible in modern Europe. Libecap and Lueck (2011b) discuss these and other rectangular demarcation systems. See also Libecap, Lueck and O’Grady (2012), Powell 1970, and Williams 1974.

\(^6\) Townships under the RS are grid locations. They are different from the small political jurisdictions also called townships that are found in many U.S. counties. The RS system is officially known as the Public Land Survey System or PLSS; [http://www.nationalatlas.gov/plssm.html](http://www.nationalatlas.gov/plssm.html).

\(^7\) Some of the earliest surveys in the rectangular system had slightly different numbering systems but by the mid 1800s this system was in place (see Thrower 1966). Canada’s system uses a slightly different numbering system but has 36 sections in a township.

\(^8\) For example, the Seventh Township north of the baseline and Third Township west of the 1\(^{st}\) Principal Meridian would be T7N, R3W, 1\(^{st}\) Principal Meridian.
Proceeding westward across the federal domain, the system was made more uniform by establishing one major north-south line (principal meridian) and one east-west (base) line that control descriptions for an entire state or region. The meridians and baselines are defined by longitude and latitude.  

**B. California’s Demarcation Path**

The history of California land demarcation can be divided into three pieces. First, is the demarcation using MB under Spain and Mexico. Second, is the establishment of the RS under American rule. Third, is the adjudication of the Mexican title when it was challenged by American settlers.

**Demarcation under Spain and Mexico**

In 1521 the Spanish conquered the Aztecs and established the viceroyalty called “New Spain” which later became Mexico. Under Spanish rule the King of Spain gave grants for very large tracts of land that laid the foundation for three forms of settlement -- presidios, pueblos and missions -- meant for colonization purposes. Veterans of the Spanish Army petitioned the Governor for very large unoccupied tracts of land outside of presidio and pueblo boundaries which came to be known as ranchos (large ranches) and their boundaries demarcated according to the discretion of the owners (Robinson 1948).

In 1821 when the Mexican Republic took over California from Spain, the Mexican government was faced with the problem of filling several empty lands with people (Corbett 1950). To encourage settlement in the northern frontier and stimulate agricultural

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9 County lines frequently follow the survey, so most counties in the western two-thirds of the US that are highly linear and often rectangular. Individual properties tend not to overlap county boundaries in order to designate administrative jurisdiction and taxing authority. See Hubbard (2009) on political jurisdictions and borders.

10 *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. Although the Spanish had claims to California from the 1500s they did not establish significant settlements until the late 1700s (Morris 1994).
development the Mexican government liberalized the nation’s land policy (Hornbeck 1976). Robinson (1948) noted that Mexican governors had the authority to grant vacant lands to contractors, families and private persons and this made available over 10 million acres of land to Mexican citizens and foreigners (Gaffey 1975). Settlers who were previously living in presidios and pueblos took advantage of this granting of land by the government (Robinson 1948). A total of 750 grants were made covering a total area of more than 12 million acres (Clay 2008). The location of all the land grants is shown in Figure 3.

**Figure 3**

Mexican settlers demarcated boundaries of the ranchos using an indiscriminant method (akin to MB). Such indiscriminant or MB methods were also used to demarcate plots within the ranchos. At the time, however, there was an almost complete absence of professional surveyors (Robinson 1948). The internal subdivision of such private property was 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

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11 Allen (1991) similarly argues that homesteading in the US was designed to increase settlement rates and thereby lower land enforcement costs in frontier areas.
12 Applicants for land grants had to petition the governor for a piece of land with requisite documentation. Among other things these documents had to include a description of the land by a hand-sketch map (diseño) of the boundaries and the land’s natural features. The map and land description were usually vague because they referred 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.
13 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 landmarks 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).
permanent-like trees, groves and streams. As a result boundary disputes were common during the Mexican era (cites).\textsuperscript{14}

\textit{Implementing the Rectangular System}

The granting of land by the Mexican government came to an end in 1846 with the beginning of the Mexican-American War. In 1848 the US, under the Treaty of Guadalupe Hidalgo, gained control of Mexican lands including California. After California became a state in 1850 Congress provided for the survey of federal lands under the US rectangular system and required that the Surveyor General in California survey private land claims and federal lands (Robinson 1948).

The rectangular system was implemented for all lands not previously demarcated under the Spanish and Mexican rule. Hubbard (2009) describes the implementation of the principle meridians in California that govern the RS. In 1851 the first meridian -- the Mount Diablo Principle Meridian -- was established near San Francisco. Two more meridians -- San Bernardino in 1852 (governing southern California) and Humboldt (governing far northern California) in 1853-- were soon established to fully cover California (see Figure 4).\textsuperscript{15} The RS demarcation proceeded from these points of origin and worked outward, and around the ranchos, to cover the entire state.

During the latter half of the 19\textsuperscript{th} century American settlers could obtain land in California and regions under the Pre-Emption Act, the Homestead Act, Desert Land Act and other related land disposal law. Legislation in 1851 and 1852 entitled California to 500,000 acres of public land for internal improvements, 5,534,293 acres for schools, 2,193,965 acres of swamp land,

\textsuperscript{14} 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. Source: \url{http://www.co.marin.ca.us/depts/lb/main/crm/maps/index.html} accessed on 14th May 2009.

\textsuperscript{15} The Surveyor General of California established three Initial Points- these were established 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. Source: \url{http://www.mdia.org/mdiaipt.htm}
6400 acres for public buildings, 46,080 for a university and 150,000 acres for an agricultural college under the Morrill Act of 1862 (Gates 1975).\textsuperscript{16}

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. As the RS was implemented in California, the land demarcated under the Spanish and Mexican land grants came up were omitted from the US system. Figure 4 shows where the land not covered by Ranchos was divided up according to the US Rectangular Survey method. Figure 5 shows an example of how ranchos were subdivided using MB and RS filled in the remaining land area. The current day satellite photo shows that MB demarcation still persists in those parts of California that were settled under Mexican and Spanish law.

\textbf{Figures 4 and 5}

According to 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 practice, however, the process by which the RS was implemented and Spanish-Mexican titles were verified was a long and tedious one and one that complicates our empirical analysis. The primary reason was that the rapid settlement of California during and just after the Gold Rush led to squatting and other efforts to claim land before legal institutions were in place to clarify rancho title to demarcate the non-rancho land. As noted above, the points of origin for the RS were not established until 1851-53. Also, California did not follow the normal practices of managing state lands because a state administering agency was not created until 1858 (Gates 1875).

\textsuperscript{16} The procedure followed in other states for the management of state lands was to delegate the responsibility to a land administering agency for selecting land, setting up entry books for each type of grant, transmitting the location to the federal district offices and to the General Land Office in Washington. After approval the title went to the state and then it could begin accepting purchase applications (Gates 1975).
Rancho Title Disputes

Because of the rush of settlers and the rapid increase in the demand for land squatting became prevalent and this led to competing claims for rancho land even before the RS was implemented. Between 1853 and 1862 squatters were allowed to preempt on un-surveyed land in several states including California (Allen 1991). In effect, Congress granted squatters the right to preempt on un-surveyed land while the RS was being implemented. During this process many squatters located on or near Mexican land grants with contentious boundaries. Where ranchos were encountered, disputes arose and created confusion as to which lands were available for settlement or not (Hornbeck 1976, Clay 2010).

Clay (2010) finds that as land grant boundaries were resolved, it became clear that most land could not be preempted or homesteaded and correspondingly, the share of 160 acre farms increased in non-land grant townships between 1860 and 1870.

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 (known as the California Land Commission) which adjudicated the claims. The 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. Costly legal processes encumbered land claims to ranchos (Clay and Troesken 2006). If a claim was deemed

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17 Gates (1975) on page 162-163 talks of a certain Robert Fulton Jr. who was ejected when it was realized that he settled upon land that was part of Mexican claims. Pisani (1994) describes one example of how a large rancho owner - Thomas O. Larkin - faced such trespassers in 1852, when nine families claimed preemption rights to parts of his rancho and they also stripped away the property’s timber. Even though the land commission and district court sustained Larkin’s claim, he had, in the meantime, bought out many of these squatters fearing a reprisal; he hoped that such an approach would persuade the squatters to purchase their claims clear title was secured through the legal process.

18 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 only 604 of the 750 claims were eventually approved by the Board of Land Commissioners (http://www.sos.ca.gov/archives/level3_ussg3.html accessed on May 14, 2009).
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 under the RS (Hornbeck 1979).

The California Land Commission was established in large part to adjudicate these title disputes. The Commission ultimately confirmed approximately sixty-seven percent of the rancho claim cases; amongst those cases that were appealed, the district courts confirmed eighty-nine percent of all claims and eighty percent of the claims in California were patented (Clay and Troesken, 2006). The patenting rate differed by county- for instance Ventura had a hundred percent while Los Angeles had a seventy seven percent rate. Clay and Troesken (2006) attribute the low patenting rate to the size of the grant, the year it was first granted and whether or not the claimants had an expediente- a record of the grant being issued by the governor of the time. Claimants faced costly litigation under the Land Commission’s and federal district courts’ confirmation and patenting process and in many cases were driven to sell their land after incurring large debts.¹⁹

Under federal law the claims falling within land grants that did not get their boundary claims approved by the Land Commission, were finally made a part of the public domain and available for homesteaders with allowable claims of up to 160 acres. Given the financial burden on the rancho owners of proving boundary claims to the Land Commission, many of them sold their properties to Americans who then sub-divided the land and sold it to new settlers (Pitt and Gutierrez, 1999). According to Robinson (1948), large tracts of private land grants (i.e., ranchos)

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¹⁹ Clay and Troesken (2005) discuss one instance of the owner of Rancho San Pedro in Los Angeles who apparently incurred an expenditure of about twenty thousand dollars in obtaining a patent.
were sub-divided using grid systems for demarcation, in areas such as Los Angeles, though these grids were not part of the RS.

By the middle of the 1850s California was a state with both MB and RS systems coinciding. The RS in the United States had been developed and perfected for over a half century and was well established. Compared to the RS studied in Ohio (Libecap and Lueck 2011b) the RS in California was much improved in terms of consistent surveying and address systems. The MB system in California was more haphazard that MB in the eastern US and also confounded by the large scale title problems to the ranchos themselves. In our empirical analysis we recognize all of these issues.

III. ECONOMICS OF LAND DEMARCATION SYSTEMS

We develop an economic framework for a comparative analysis of RS and MB that assumes land demarcation is exogenously imposed, thus constraining the parties differentially under each system. We examine the optimal configuration of land parcels, land disputes, land markets, land values, and long-term land value and use under both MB and RS. 20

A. Demarcation Basics: Parcel Shapes, Sizes, Alignment, and Topography

The individual parcel demarcation decision will depend on both the expected value of plot productivity, demarcation costs, and the demarcation regime. The innate characteristics of the land will partly determine its productivity and the cost of demarcating each parcel. In particular, topography or ruggedness plays an important role. More rugged terrain will have lower productivity and higher surveying and policing costs. The demarcation regime will constrain the size, shape, and alignment (i.e., spatial or directional orientation) of the parcels.

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20 We draw on the analysis in Libecap and Lueck (2011b) and Libecap, Lueck and O'Grady (2012).
Under RS in the United States, as noted, demarcation established a grid of identical-sized and N-S aligned squares. Under MB, however, shape, size, and alignment were at the discretion of the original claimant.

We define a net value function for a parcel of land as $V = y(a, p; t, l) - c(a, p; t, l)$ where $a$ is the area of the parcel (e.g., acres) $p$ is the parcel perimeter (e.g., miles); $t$ is an indicator of the land’s topographical features (e.g., ruggedness or land quality), and $l$ indicates the land demarcation regime (MB or RS). The value of the parcel is $y = y(a, p; t, l)$ and shows that value depends on parcel shape and size $(a, p)$ as well as on land characteristics and the demarcation system. Similarly, $c = c(a, p; t, l)$ is a demarcation and enforcement cost function\(^{21}\) that also depends on the choice variables $(a, p)$ and the parameters $(t, l)$.\(^{22}\) Topography and the demarcation system will affect the size and perimeter choices i.e., $p = p(t, l)$ and $a = a(t, l)$ and parcel alignment, as well as directly affect both value and demarcation costs.

Under each regime initial landholders pick the size and shape $(a, p)$ to maximize $V = y(a, p; t, l) - c(a, p; t, l)$. The next section examines the implications of these demarcation choices as well as the implications for land markets and values generated by the different demarcation regimes under varying topography.

**B. Initial Parcel Demarcation**

To consider the comparative implications of the two land demarcation systems on initial demarcation and on land markets we make the following assumptions. First, we assume that under each exogenously imposed regime there is a large tract of land of $A$ acres, whose external boundary is enforced collectively or otherwise by a sovereign. Second, within this large tract,

\(^{21}\) We combine demarcation and enforcement costs together for convenience.

\(^{22}\) We assume $y_a > 0$, $y_t < 0$, $c_a > 0$, and $c_t > 0$. 
there is a group of non-cooperative agents that claim and enforce separate plots in order to maximize the value of their land, net of demarcation and enforcement costs. Each claimant can only choose and demarcate a single parcel. Within the external borders, there is no coordination or contracting among claimants.23

**Demarcation under MB**

Under MB each claimant chooses the number of acres to claim and the length of parcel boundary to enforce it in order to solve

\[
\max_{a_i, p_i} V_i = y_i(a_i, p_i; t_i, l_i) - c_i(a_i, p_i; t_i, l_i) \quad \text{s.t.} \quad \sum_{i=1}^{n} a_i = A.
\]

Under MB there are few system constraints on the size and shape of the claims, and no mechanism to coordinate alignment of individual parcels. The solution to the parcel demarcation problem will depend on the structure of value and cost functions, and importantly, on how topography affects these functions. The non-cooperative Nash equilibrium solution to this problem defines the optimal size \((a, p)\) pair -- \((a^*, p^*)\) -- which implies a plot shape.24 Consider the simple case in where claimants have the same productivity \((v_i = v_j, i \neq j)\), the same enforcement costs \((c_i = c_j, i \neq j)\), and value does not depend on topography or shape. The claimant's problem is to simply minimize border demarcation and enforcement costs, constrained by the productivity of the land.

Because we have introduced a binding land constraint, \(A\), so that all land is to be included in tangent parcels and because rectilinear plots have optimal production advantages for agriculture and urban use (Barnes 1935), Lee and Sallee (1974), and Amiama, Bueno, and

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23 We assume simultaneous claiming and we ignore the optimal time to claim under first possession rules (Lueck 1995).

24 In general an \((a, p)\) pair will not fully define a shape - angles and side and planar topography would all be required - but for our purposes this simpler view is appropriate.
Alvarez (2008), we predict square parcels. There are several reasons why squares are the expected optimal parcel shape under MB when the land is flat. Squares fill the interstitial space or gaps between parcels, which minimize waste. They have relatively low perimeter-to-area ratios \( p/a \) and thus have low demarcation and enforcement costs. Survey and fencing (enclosure) costs are lower for plots with fewer angles and longer straight boundaries (Johnson 1976).

Deviating from flat topography, however, will alter the net value function by affecting both land value and demarcation costs. If demarcation and enforcement costs (surveying-fencing-policing) are increasing in ruggedness and land value are declining in ruggedness, borders will roughly follow topography. We expect the non-cooperative Nash equilibrium to yield a pattern of parcel sizes and shapes that depends on the character of the land and of the potential of claimants (farming productivity, violence and monitoring productivity). The nature of topography can be easily illustrated. For example, let \( (a^*, p^*) \) be the equilibrium pair for \( t = t^0 = 0 \) (i.e., flat land) and \( (a^{**}, p^{**}) \) be the equilibrium pair for \( t = t' > 0 \). This necessarily implies that \( v(a^*, p^*, t') < v(a^{**}, p^{**}, t') \) which shows that allowing the flexibility to adapt to terrain is valuable.

In addition because MB does not coordinate or otherwise constrain the spatial structure of individual parcels, alignment will be solely the choice of the individual claimant. Under MB, the lack of coordination among claimants means that individual parcels will not have a common alignment. Even in the case where the land is flat and the optimal shapes are squares there is no reason to

\[25\text{ Regular polygons maximize the area enclosed by a given perimeter and thus have the lowest } p/a \text{ ratio for any } n\text{-sided polygon but only three regular polygons -- triangles, rectangles (squares), and hexagons -- can create patterns, with a common vertex and have no interstitial space (Dunham 1994).}\]

\[26\text{ It is well known that a circle will maximize the area for a given perimeter, providing the lowest } p/a \text{ ratio, thus if enforcement costs simply depend on the perimeter or the perimeter relative to area (e.g., } c=kp) \text{ we should see circular plots as a Nash equilibrium under MB. This is the solution to the famous isoperimetric problem (Dunham 1994). Adjacent circles, however, are tangent only at one point and leave gaps of land undemarcated, an issue we examine below. Further, circles are costly shapes for agricultural use and are rarely observed in plots. The optimal shape of plots under MB is discussed in more detail in Libecap and Lueck (2011a).}\]
expect a grid of squares. The coordinate grid is a public good that will not be provided, unless there is contract among claimants, perhaps in the form of a developer.

**Demarcation under RS**

Initial demarcation under RS is distinct from that under MB. The land is surveyed by the sovereign into squares prior to allocation and, in the American RS, regardless of topography. Formally, the square-parcel constraint means \((a, p) \rightarrow p/\sqrt{a} = 4\). Unlike MB, claimants under RS do not explicitly choose area and perimeter \((a, p)\) but are constrained by the system so that the choice under RS is to pick a (square) parcel that maximizes difference between 

\[ V = y(a, p; t, RS) \]

and the acquisition costs of the parcel. Demarcation costs are zero for the claimant. Because RS demarcation does not allow for deviation from squares the value of parcels will decrease and demarcation costs (for the sovereign) will rise, however, with more rugged topography.

**C. Aggregation: Total Value and Land Markets**

The previous analysis considered initial demarcation of individual parcels under MB and RS. In this section we examine the net value of aggregated land under both systems and also examine how each system affects the market for land after initial demarcation.

**Total Value of the Land in a System**

As above, we assume the region governed by either MB or RS is \(A\) acres, split into \(n\) parcels, each of size \(a\), so that \(A = na\). We incorporate a temporal dimension to account for difference in setup and continuation costs for the two regimes. Under MB the net value of the land is the sum of individual values and costs, less the continuing costs associated with

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\(^{27}\) We focus on the ratio \(p/\sqrt{a}\) to keep units the same in our empirical analysis. The simple derivation is: let \(s\) be the side of a square, then \(p/a = 4s^2/s^2\) so \(p/s = 4\).
adjustments resulting from the lack of coordination, so that the total present value of the land in the region is:

\[ V^{MB} = \int_0^T \left( \sum_{i=1}^n v^*_\tau(p^*, a^*; t) - C^{MB}_\tau(A, a^*; t) \right) e^{-r\tau} \, d\tau - c_0(a^*, p^*; t), \]

where \( v^*_\tau = v^*_\tau(p^*, a^*; t) \) is the optimal parcel value under MB at time \( \tau \), \( T \) is the time horizon, \( r \) is a discount rate, \( C^{MB}_\tau(A, a^*; t) \geq 0 \) are the continuing costs of MB, including individual enforcement, parcel border disputes, and other costs associated with misaligned plots; and \( c_0(a^*, p^*; t) \) is the one-time demarcation cost function. Under MB land demarcation and output begin immediately at time \( \tau = 0 \) and the continuing costs associated with MB are assumed to be increasing in the size of the region \( (A) \) and rising over time \( (\tau) \) as these problems accumulate.

The total value under RS has a different structure from MB because it is a coordinated regime. We assume the network effects of RS are such that a person’s or group’s use of the system also benefits others and that it further increases the incentive to participate (Baird, Gertner, and Picker 1994; Farrell and Klemperer 2007). The network benefits are the public goods of common addresses, survey coordination, and standardized, aligned and fixed parcel boundaries that reduce border disputes and expand the land market. These network and coordination benefits come, however, at the cost of a necessarily extensive system. Under RS there are upfront costs of design, survey, and controlling land access until demarcation is completed.

Under these assumptions the total present value of the land in the RS region is

---

28 In both total value functions (2-3) we drop the ‘l’ demarcation regime parameter since they are fixed at MB or RS.
29 Our MB – RS cost distinction is similar to Dixit’s (2003) distinction between local (informal) and large (formal-legal) trading systems, where the latter have greater setup costs like RS.
where \( \bar{v}_{it} = v_{it}(\bar{p}, \bar{a}, n; t) \) is the optimal value for parcel \( i \) under RS at time \( \tau \) where again \( \bar{p}/\sqrt{\bar{a}} = 4.0 \) under the square-parcel constraint; \( T \) is the time horizon, \( r \) is a discount rate;

\[ C_{\tau}^{RS}(A, \bar{a}; t) \geq 0 \]

is the cost of the system that occurs prior to claiming and use. Network effects are incorporated into the parcel value function, which is increasing in the number of parcels governed by the RS, where \( n = A/\bar{a} \).\(^{30}\) RS system costs are increasing in \( A \), but at a decreasing rate, revealing network economies. These costs are also increasing in topography, and the effects are greater than with MB because of the square-parcel constraint. Under RS surveying occurs prior to parcel selection, so the time horizon for generating value from the land begins at \( \tau' > 0 \).

**Land Markets: MB versus RS**

The structure of the RS value function in (3) has economic implications for land markets once RS has been adopted. Because parcel boundaries are standardized and aligned, there are fewer overlapping borders and unclaimed gaps outside property descriptions.\(^{31}\) There will be fewer legal disputes (and litigation) over boundaries and titles under RS than MB (Libecap and Lueck 2011 b).

The structure in (3) also suggests gains from centralized RS demarcation with uniformly-defined parcels and common addressing that lowers the cost of using the market and allows for reorganization of plots as conditions change (Barzel 1982). This should be observed as a greater

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\(^{30}\) We ignore the optimal choice of square parcel size, such as a section of 640 acres, and take it as a constraint that is consistent the American RS.

\(^{31}\) See Priest and Klein (1984) who similarly argue that uncertain legal rules result in more litigation.
number of market transactions under RS than MB and increase in the value of land.\textsuperscript{32} The following predictions are implied by this analysis.

\textbf{Prediction 1:}
There will be higher (per acre) land values under RS than MB.\textsuperscript{33}

\textbf{Prediction 2:}
There will be more land transactions under RS than under MB and farm size will have a lower variance under RS and MB.

\textbf{Prediction 3:}
There will be higher fraction of land improved under RS than MB.

\textit{Net Value of the RS.}

The analysis summarized by (2) and (3) indicates that it is efficient to implement RS when \( V^{RS} - V^{MB} > 0 \) and the potential net gains can be calculated with some simplifications.

First let \( \bar{V} = \sum_i \bar{V}_i \) and \( V^* = \sum_i V_i^* \). Second, assume that the land is flat \( (t = 0) \) and that the RS parcel shapes and sizes are the same as under decentralized MB \((a = a^*, \bar{p} = p^*)\) then

\begin{equation}
(4) \quad V^{RS} - V^{MB} = \int_0^T (\bar{V}_t^n(n) - V_t^*) e^{-rt} dt - \int_0^T (V_t^* + C_t^{RS}) e^{-rt} dt + c_0 + \int_0^T C_t^{MB} e^{-rt} dt.
\end{equation}

Equation (4) states that the net gain of RS over MB for a region of size \( A \) is comprised of four parts, given by the respective terms: i) the increase in land value under RS compared to MB from the time that the RS is implemented; ii) the foregone land rent during the setup period and setup costs during that period; iii) the one time MB demarcation cost; and iv) the continuing MB costs.

\textsuperscript{32} Although the RS constrained plots to be square, various US land laws authorized different size distributions (Gates, 1968). Subsequent market activity, however, would lead to subdivision or aggregation of rectilinear plots to achieve optimal production sizes and we argue that the RS would smooth these market transactions.

\textsuperscript{33} As indicate above, we also predict that under RS land values will be decreasing in the ruggedness of the topography of the land and that there would be a breakeven point beyond which the gains of the RS would be offset by the costs of rigidity.
The structure in (4) is can be used to calculate the net gains from RS by coupling estimates of the RS land value effects with information on RS setup costs.

IV. Empirical Analysis

In this section we test our predictions against data taken from U.S. Census and other sources. Our empirical analysis focuses on the period (1860) just after the rectangular system was implemented and when the first detailed US Census data on agriculture became available. As noted, historical forces created a landscape in California with both metes and bounds and rectangular systems providing a natural experiment in land demarcation. The analysis begins with a description of the specific study area in California. Next we describe in detail data and our empirical strategy for identifying the effects of land demarcation on land markets. We then present a wide array of empirical estimates of the effects of demarcation on 19th century California land values and discuss the implications and limits of these estimates.

A. The California Study Area

To exploit California’s natural experiment we choose areas that are covered entirely by rancho land or the RS grid system. The 19th century US Census data does not indicate whether the townships were subdivided by the RS grid system or not, so we use 19th century county maps to determine the type of demarcation system in the townships (see figures A.4- A.9 in the Appendix). We selected townships that were entirely rancho land (MB) or demarcated by the RS grid system. Table 2 shows these townships, their land demarcation system, the counties in which they lie and the number of sampled farms in each township. Figure 6 shows the location of the townships. Note that these townships are located in central California near the coast and

34 These are 19th century county maps that are digitized and geo-referenced the township boundaries onto a county map of California using Arc-GIS software. We are currently expanding the data set using GIS-based data and other sources.
the Central Valley region. The right hand side panel shows a magnified image of the townships demarcated by MB (shaded yellow) and by RS (shaded orange). Within these townships we sampled 20% of the farms using the Agricultural Census data sheets.

**Table 2 and Figure 6**

**B. Data**

The process above allows us to create a data set in which each observation is a farm. Each observation includes farm-level information from the 1860 Census, including information on outcomes (e.g. farmland values, fraction of improved acreage, farm size). Farmland value is our main measure of economic performance available at the individual farm level. Other farm and farmer information are also available at the farm level from the Census. These farm level data are supplemented with data available only at the township or county level, such as natural parameters (e.g., topography, soil quality), and economic parameters (e.g., distance to markets, population). To identify the demarcation systems we create a binary variable indicating whether the farm lies in an RS or MB-demarcated township. Table 3 shows the variable definitions and summary statistics of the entire sample of 427 farms within the 16 townships summarized in Table 2. The Appendix describes the data and their sources in more detail.

**Table 3**

Information on land characteristics come from a variety of sources. For soil quality information we use the California Department of Conservation FMMP program’s data for generating average measures of land quality at the township level.\(^{35}\) To quantify topography of the land we use a measure of average slope of the land for each township and created a variable **RUGGEDNESS.** Ruggedness measures the slope of land in percent and ranges from 0 (flat land) to

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\(^{35}\) See: [http://www.conservation.ca.gov/dlrp/FMMP/Pages/Index.aspx](http://www.conservation.ca.gov/dlrp/FMMP/Pages/Index.aspx). These data are from the year 2002 though there is no reason to believe there have been systematic change in inherent land characteristics since the 1860s. ArcGIS software was used generated topographical and soil quality data at the township-level. Figure A.3 in the Appendix shows the mapping of farmland quality carried out by the FMMP program.
A grade more than 5% is very steep for a highway, and productive farmland typically is found with slopes of 0% - 5% (FAO 1993). The mean value of RUGGEDNESS in our data is 7.7%.

We also use data on market and demographic characteristics to create a variety of control variables. These variables include distances to market, county populations, and demographic characteristics of local populations. To measure distance to markets we use variables that measure the linear distance from the center of a township to the county seat and this average is applied to all farms within the township. Population data were 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.

The uncertainty about rancho titles creates a potential bias against that could overestimate the effect of RS versus MB demarcation. We use two variables to measure this title uncertainty. Both rely on information about the title patenting process described in section II. First, we use a variable indicating the number of acres that were not confirmed by the Land Commission by the year 1860 as a proportion of the number of acres in a township. Second,

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36 Figure A.1 and A.2 in the Appendix show the Digital Elevation Models (DEM) used to arrive at these measures. at surveyors, engineers, and other land professionals typically describe terrain in terms of “percent slope” which refers to the change in elevation for a unit change of horizontal distance. A 90 degree angle has a % slope of +∞. The formula for converting percent slope into angle degrees is: \( \text{angle} = \arctan \left( \frac{\text{slope}}{100} \right) \) where angle is in degrees and \( \arctan \) is the trigonometric function.

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

38 The uncertainty in the confirmation/patenting process is not measured perfectly by the unpatented ratio. For this one would have to procure data on unpatented acres at the farm level. Data on patenting is only available at the broader rancho level and it is difficult to determine where exactly a particular farm lies in a township or a rancho using 19th century township maps. In the data it was frequently observed that some ranchos were patented by 1860 and some were not, and also that rancho boundaries extended across townships. Hence, admittedly, the unpatented ratio captures only a limited extent of the uncertainty in property rights at the farm level.
we use the number of years since the rancho has had a patented title as established by the Land Commission.

**Table 4**

Table 4 shows the summary statistics by MB and RS regions. The table shows 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.\(^{39}\) This is consistent with Prediction 1 that per acre farmland values are expected to be higher for RS farms. MB farms are seen to be slightly more rugged than RS farms on average. MB farms are also closer, on average to markets, in terms of distance from county seats and from San Francisco. The table also shows that the population characteristics (% white, % native born) of RS and MB townships are quite similar though statistical distinct.

**C. Estimates of Demarcation Effects**

To estimate the effects of land demarcation systems (MB versus RS) on economic performance we use the following equation

\[(5) \ln y_i = \theta R S_i + X_i \beta + \mu_i\]

where \((y_i)\) is an outcome measure (e.g., farmland value, fraction of improved land) for the \(i^{th}\) farm; \(R S_i\) is a binary demarcation parameter (=1 if RS, = 0 if MB) for the \(i^{th}\) farm; \(^{40}\) \(\theta\) is the an unknown coefficient, \(X_i\) is a row vector of exogenous variables (e.g, land ruggedness, distance to market); \(\beta\) is a column vector of unknown coefficients including a slope; and \((\mu_i)\)

\(^{39}\) 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, are shown in the Appendix, and indicate that the two variable specifications are very close to each other in magnitude and the correlation between them is close to one.

\(^{40}\) 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.
is an error term. In general, we predict that $\theta > 0$, or that RS will have a positive impact on economic outcomes such as farmland values. We estimate (5) using a variety of specifications and samples and report them below.

**Farmland Values**

The estimates of farmland values are presented in Table 5.\(^{41}\) The control variables include measures of land characteristics, land title uncertainty, market access, and county population. The results show that RS demarcation has a positive and statistically – consistent with Prediction 1 - significant effect on farmland values, and is robust across specifications. Just as important these parameter estimates indicate that the effect is positive and large, generally exceeding 100%.\(^{42}\)

**Table 5**

The estimates in Table 5 also show that the estimates are robust to the inclusion of various control variables. The estimates show that RUGGEDNESS generally has no effect (or very trivial) on land values but that the interaction between RS and has a general negative effect.\(^{43}\)

The estimates for the rancho title uncertainty variables are mixed. The coefficient estimates for UNPATENTED RATIO are negative but not statistically significant indicating that this title uncertainty did not affect farmland values.\(^{44}\) Our alternative title uncertainty variable, however, YEARS SINCE RANCHO TITLE GRANTED, is statistically significant and actually increases the land value estimates.

\(^{41}\) We also estimate (2) using the levels of farmland values as the dependent variables and find similar effects.

\(^{42}\) Libecap and Lueck (2011b) found RS effects to range from 20-40% in their Ohio data. One explanation for this larger effect in California compared to the RS system in Ohio is that the RS in Ohio was new and implemented somewhat inconsistently and thus represented a rather imperfect version of RS compared to what was ultimately established in California more than a half century later.

\(^{43}\) In their Ohio study Libecap and Lueck (2011b) found that RUGGEDNESS and RS*RUGGEDNESS were more robust factors in the determination of land values.

\(^{44}\) This is possibly due to the inaccuracy of this measure (as discussed earlier). Arc-GIS software was used to digitize the old township maps and often the boundaries of the Ranchos were not clearly demarcated on these maps.
**Farm Size Distribution and Farmland Investment**

Prediction 2 states that RS lands will have less variance in farm size because the land market will be more efficient. Table 4 shows some supporting evidence, as the mean size in of the MB farms is 472 acres as opposed to 266 acres in RS farms but it also shows that the extremes differ in the two demarcation systems. The largest farm size in MB regions is greater than 20,000 acres. We also test this prediction by equation (5) using \( TOTAL\ FARM\ ACRES \) as the dependent variable. The estimates are shown in Table 6 (right panel) and show that the RS coefficient is about the same as the mean difference and it is also negative and statistically significant.45

**Table 6**

Prediction 3 states that RS lands will generate more investment in land improved. The mean values of improved and unimproved acres in Table 4 show this to be the case. 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 6 (left panel) shows the estimate (5) where the dependent variable -- IMPROVED ACRES -- is the proportion of total farmland acres that are improved. The sign of the RS coefficient is negative as predicted and statistically significant.46 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.

45 In future work we will estimate the effect of RS demarcation on the variance in farm size.
46 This finding is similar to Hornbeck’s (2010) finding that as property rights improved with the advent of barbed wire there was an increase in the amount of improved farmland.
Adjacent RS-MB Townships Sub-samples

We further test our prediction about land values by examining a smaller sample of farms from geographically adjacent townships. In this sample there are two sets of RS -- MB adjacent townships are: Redwood (RS) -- Santa Clara (MB) in Santa Clara County and Vallejo (RS) – Benicia (MB) in Solano County. In figure 8 the Solano County townships are circled as 1 and the Santa Clara County townships are circled as 2.

Figure 7, Tables 7-8

Table 7 provides summary statistics of this sub-sample of farms by land demarcation system. These statistics from this small sample shows that unimproved acres are higher in MB farms of Santa Clara County and in both counties the RS farms have higher average land values. 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.

We next estimate the specification of equation (5) using OLS with farmland value per acre as the dependent variable. The results provided in Table 8 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.
V. SUMMARY AND CONCLUSION

The unique colonial history of California generates a natural experiment in land demarcation that provides an opportunity to examine the effect of property rights institutions on economic performance. Our preliminary estimates show that RS substantially increases the value of land compared to similar land governed by MB. The parameter estimates are seen to be robust with little fluctuation in their values even after adding in controls for exogenous factors. Unlike Libecap and Lueck (2011b) topography has little direct impact on land values, though we find that more rugged terrain reduces that advantage of RS over MB.

Our findings provide further evidence not only are property rights institutions important in determining economic outcome but that the details of these institutions is also important. Further work will expand the data set and refine the estimates presented here.
REFERENCES


Libecap, Gary D. Dean Lueck, and Trevor O’Grady. 2012. “Large Scale Institutional Changes: Land
Demarcation within the British Empire.” Journal of Law and Economics in press.
Ormsby xxx 2010. xxxx
US Agricultural Census of California, 1860. Microfilm reels showing township-level farm data.
Table 1: Important Dates on California Land Demarcation

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1521</td>
<td>New Spain established</td>
</tr>
<tr>
<td>1821</td>
<td>Republic of Mexico established</td>
</tr>
<tr>
<td>1848</td>
<td>Treaty of Guadalupe Hidalgo defines the terms of the US victory over Mexico</td>
</tr>
<tr>
<td>1850</td>
<td>California becomes a state on September 9.</td>
</tr>
<tr>
<td>1851</td>
<td>California Land Act creates process for patenting rancho lands. Mt Diablo and San Bernadino principle meridians are established.</td>
</tr>
<tr>
<td>1860</td>
<td>First US Census of California as a state.</td>
</tr>
</tbody>
</table>

Table 2: RS and MB Townships in California Study Area

<table>
<thead>
<tr>
<th>County</th>
<th>Township</th>
<th>Demarcation system</th>
<th>Farms in sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alameda</td>
<td>Alameda</td>
<td>MB</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Brooklyn</td>
<td>MB</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>MB</td>
<td>69</td>
</tr>
<tr>
<td>Santa Clara</td>
<td>Redwood</td>
<td>RS</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Santa Clara</td>
<td>MB</td>
<td>34</td>
</tr>
<tr>
<td>Solano</td>
<td>Benicia</td>
<td>MB</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Vallejo</td>
<td>RS</td>
<td>18</td>
</tr>
<tr>
<td>Sonoma</td>
<td>Analy</td>
<td>MB</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Sonoma</td>
<td>MB</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Vallejo</td>
<td>MB</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>MB</td>
<td>33</td>
</tr>
<tr>
<td>Yolo</td>
<td>Washington</td>
<td>RS</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Merritt</td>
<td>RS</td>
<td>39</td>
</tr>
<tr>
<td>Fresno</td>
<td>Township #1</td>
<td>RS</td>
<td>17</td>
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<tr>
<td>Sutter</td>
<td>Nicolaus</td>
<td>RS</td>
<td>14</td>
</tr>
<tr>
<td>Marin</td>
<td>San Antonio</td>
<td>MB</td>
<td>15</td>
</tr>
</tbody>
</table>

Sources: Rumsey (2003) and US Census (1860).
### Table 3: Summary Statistics of the Full Sample (427 Observations)

<table>
<thead>
<tr>
<th>Variable Type</th>
<th>Variable Definition</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variables</strong></td>
<td>Farmland value per acre (1860 $)</td>
<td>26</td>
<td>16</td>
<td>0</td>
<td>1,007</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Improved acres of farmland</td>
<td>234</td>
<td>120</td>
<td>0</td>
<td>5,000</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>Unimproved acres of farmland</td>
<td>178</td>
<td>0</td>
<td>0</td>
<td>20,000</td>
<td>1,051</td>
</tr>
<tr>
<td><strong>Independent variables</strong></td>
<td>Farmland category (1-8 in increasing fertility)</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ruggedness (average % slope)</td>
<td>7.77</td>
<td>8.70</td>
<td>1.08</td>
<td>22.62</td>
<td>5.58</td>
</tr>
<tr>
<td><strong>Land characteristics</strong></td>
<td>Distance (miles) to County seat from township center</td>
<td>17.77</td>
<td>15.70</td>
<td>3.44</td>
<td>61.43</td>
<td>11.99</td>
</tr>
<tr>
<td></td>
<td>Distance (miles) to San Francisco from township center</td>
<td>43.81</td>
<td>37.51</td>
<td>10.1</td>
<td>115.48</td>
<td>25.30</td>
</tr>
<tr>
<td></td>
<td>County population in 1860</td>
<td>8770</td>
<td>8927</td>
<td>4</td>
<td>11912</td>
<td>3002</td>
</tr>
<tr>
<td><strong>Rancho title security</strong></td>
<td>Rancho acres in township not patented by 1860</td>
<td>17,039</td>
<td>10,610</td>
<td>0</td>
<td>88,675</td>
<td>20,027</td>
</tr>
<tr>
<td><strong>Population ethnicity</strong></td>
<td>Fraction native population in county</td>
<td>0.736</td>
<td>0.719</td>
<td>3</td>
<td>0.868</td>
<td>0.107</td>
</tr>
<tr>
<td></td>
<td>Fraction foreign population in county</td>
<td>0.264</td>
<td>0.281</td>
<td>2</td>
<td>0.407</td>
<td>0.107</td>
</tr>
<tr>
<td></td>
<td>Fraction white population in county</td>
<td>0.943</td>
<td>0.976</td>
<td>7</td>
<td>0.993</td>
<td>0.149</td>
</tr>
</tbody>
</table>

Sources: See Data Appendix
**TABLE 4: COMPARISON OF RS (n=128) & MB (n=299) SAMPLES**

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Mean</th>
<th>MB-RS t-value</th>
<th>Min</th>
<th>Max</th>
</tr>
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<tbody>
<tr>
<td><strong>RS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>t-value</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmland value per acre</td>
<td>47</td>
<td>17</td>
<td>-3.46*</td>
<td>6</td>
</tr>
<tr>
<td>Improved (acres)</td>
<td>202</td>
<td>247</td>
<td>0.99</td>
<td>2</td>
</tr>
<tr>
<td>Unimproved (acres)</td>
<td>65</td>
<td>225</td>
<td>2.20*</td>
<td>0</td>
</tr>
<tr>
<td>Fraction unimproved</td>
<td>0.21</td>
<td>0.32</td>
<td>2.99*</td>
<td>0</td>
</tr>
<tr>
<td>Total acres farmland</td>
<td>266</td>
<td>472</td>
<td>2.42*</td>
<td>3</td>
</tr>
<tr>
<td>Farmland quality</td>
<td>6</td>
<td>4</td>
<td>-12.06*</td>
<td>3</td>
</tr>
<tr>
<td>Ruggedness (% slope)</td>
<td>4.21</td>
<td>9.26</td>
<td>8.09*</td>
<td>1.08</td>
</tr>
<tr>
<td>Market distance</td>
<td>24.19</td>
<td>15.08</td>
<td>-6.22*</td>
<td>11.02</td>
</tr>
<tr>
<td>SFO distance</td>
<td>67.80</td>
<td>33.77</td>
<td>-13.66*</td>
<td>25.93</td>
</tr>
<tr>
<td>County population</td>
<td>5647</td>
<td>10078</td>
<td>18.13*</td>
<td>3390</td>
</tr>
<tr>
<td>Unpatented acres</td>
<td>0</td>
<td>24,171</td>
<td>21.06*</td>
<td>0.706</td>
</tr>
<tr>
<td>Fraction native born</td>
<td>0.795</td>
<td>0.712</td>
<td>-10.29*</td>
<td>0.593</td>
</tr>
<tr>
<td>Fraction white population</td>
<td>0.886</td>
<td>0.966</td>
<td>3.42*</td>
<td>0.217</td>
</tr>
</tbody>
</table>

* Indicates that the mean difference is statistically significant at the 5% error level.

Sources: See Data Appendix
### Table 5: Parameter Estimates from OLS Regression Models (Full Sample)

**Dependent variable:** Ln (Farmland Value Per Acre)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERCEPT</strong></td>
<td>2.861</td>
<td>2.680</td>
<td>3.070</td>
<td>5.336</td>
<td>6.488</td>
<td>2.876</td>
<td>5.523</td>
<td>0.893</td>
<td>0.941</td>
<td>3.067</td>
</tr>
<tr>
<td>(1.243)^*</td>
<td>(0.978)^*</td>
<td>(1.507)^*</td>
<td>(0.560)^*</td>
<td>(0.432)^*</td>
<td>(1.208)*</td>
<td>(0.590)*</td>
<td>(0.830)*</td>
<td>(0.739)*</td>
<td>(1.509)*</td>
<td></td>
</tr>
<tr>
<td><strong>Demarcation:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>2.374</td>
<td>1.430</td>
<td>1.180</td>
<td>1.904</td>
<td>3.420</td>
<td>2.649</td>
<td>3.242</td>
<td>2.688</td>
<td>2.543</td>
<td>1.171</td>
</tr>
<tr>
<td>(1.104)^*</td>
<td>(0.853)^*</td>
<td>(1.040)*</td>
<td>(0.322)*</td>
<td>(0.210)*</td>
<td>(0.394)*</td>
<td>(0.215)*</td>
<td>(0.584)*</td>
<td>(0.497)*</td>
<td>(1.044)</td>
<td></td>
</tr>
<tr>
<td><strong>Land features:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUGGEDNESS</td>
<td>0.037</td>
<td>0.030</td>
<td>0.028</td>
<td>0.034</td>
<td>0.05</td>
<td>0.010</td>
<td>0.036</td>
<td>-0.002</td>
<td>-0.002</td>
<td>0.028</td>
</tr>
<tr>
<td>(0.038)</td>
<td>(0.054)</td>
<td>(0.051)</td>
<td>(0.019^*</td>
<td>(0.009)^*</td>
<td>(0.020)</td>
<td>(0.011)^*</td>
<td>(0.028)</td>
<td>(0.024)</td>
<td>(0.051)</td>
<td></td>
</tr>
<tr>
<td>RS * RUGGEDNESS</td>
<td>-0.116</td>
<td>-0.057</td>
<td>-0.042</td>
<td>-0.078</td>
<td>-0.149</td>
<td>-0.040</td>
<td>-0.122</td>
<td>-0.010</td>
<td>-0.019</td>
<td>-0.041</td>
</tr>
<tr>
<td>(0.075)</td>
<td>(0.063)</td>
<td>(0.078)</td>
<td>(0.025)^*</td>
<td>(0.012)^*</td>
<td>(0.026)</td>
<td>(0.016)^*</td>
<td>(0.035)</td>
<td>(0.031)</td>
<td>(0.078)</td>
<td></td>
</tr>
<tr>
<td><strong>Title uncertainty:</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rejected Claims ratio</td>
<td>-</td>
<td>-0.151</td>
<td>-0.189</td>
<td>-0.053</td>
<td>0.315</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.190</td>
</tr>
<tr>
<td>(0.880)</td>
<td>(0.772)</td>
<td>(0.341)</td>
<td>(0.117)^*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.774)</td>
</tr>
<tr>
<td># YEARS SINCE RANCHO GRANTED</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.046</td>
<td>0.016</td>
<td>0.065</td>
<td>0.057</td>
<td>-</td>
</tr>
<tr>
<td>(0.018)^*</td>
<td>(0.007)^*</td>
<td>(0.012)^*</td>
<td>(0.012)^*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Controls:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Distance</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County Population</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>% Native Born</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Farmland Quality</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Livestock Value per acre</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wheat Bushels per acre</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Model F-statistic</strong></td>
<td>31.43</td>
<td>12.41</td>
<td>17.65</td>
<td>51.33</td>
<td>223.8</td>
<td>93.65</td>
<td>153.7</td>
<td>100.5</td>
<td>172.6</td>
<td>47.57</td>
</tr>
<tr>
<td>R^2</td>
<td>0.275</td>
<td>0.207</td>
<td>0.210</td>
<td>0.333</td>
<td>0.419</td>
<td>0.385</td>
<td>0.419</td>
<td>0.358</td>
<td>0.421</td>
<td>0.213</td>
</tr>
<tr>
<td>N</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
<td>422</td>
</tr>
</tbody>
</table>

* p< 0.1. Standard errors (in brackets) are clustered at the Township level i.e. 16 clusters.
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>Y = % Unimproved land</th>
<th>Y = total acres of farmland</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERCEPT</td>
<td>0.28</td>
<td>485</td>
</tr>
<tr>
<td></td>
<td>(0.037)*</td>
<td>(82.95)*</td>
</tr>
<tr>
<td>Demarcation:</td>
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</tr>
<tr>
<td>RS</td>
<td>-0.090</td>
<td>-212</td>
</tr>
<tr>
<td></td>
<td>(0.039)*</td>
<td>(84.82)*</td>
</tr>
<tr>
<td>Land features:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUGGEDNESS</td>
<td>0.00381</td>
<td>-1.33</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(5.62)</td>
</tr>
<tr>
<td>F value (df)</td>
<td>4.50*</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td>(426)</td>
<td>(426)</td>
</tr>
<tr>
<td>R²</td>
<td>0.021</td>
<td>0.007</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at 10% error level with one-tailed t-test.
Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.
## Table 7: Comparison of RS & MB Means in Adjacent Townships Sub-Sample

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Solano County</th>
<th>Santa Clara County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RS (n=18)</td>
<td>MB (n=7)</td>
</tr>
<tr>
<td>$ Farmland value per acre</td>
<td>33.02</td>
<td>14.24</td>
</tr>
<tr>
<td>Unimproved acres of farmland</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Farmland category (1-8 in increasing fertility)</td>
<td>2.54</td>
<td>4.12</td>
</tr>
<tr>
<td>Township topography (av. % rise in slope)</td>
<td>5.06</td>
<td>10.62</td>
</tr>
<tr>
<td>Distance (miles) to County seat from township</td>
<td>17.23</td>
<td>12.09</td>
</tr>
<tr>
<td>Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (miles) to Sacramento from township</td>
<td>51.53</td>
<td>47.82</td>
</tr>
<tr>
<td>Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rancho acres in township not patented by 1860</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>26891</td>
</tr>
</tbody>
</table>

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

## Table 8: Parameter Estimates from OLS Regression Models (2-county Sample)

**Dependent Variable: LN (Farmland Value Per Acre)**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>Solano County</th>
<th>Santa Clara County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demarcation:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>1.85</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>(0.12)*</td>
<td>(0.22)</td>
</tr>
<tr>
<td>Land features:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FARMLAND QUALITY</td>
<td>0.62</td>
<td>1.048</td>
</tr>
<tr>
<td></td>
<td>(0.035)*</td>
<td>(0.07)*</td>
</tr>
<tr>
<td>F value (d.f.)</td>
<td>878* (24)</td>
<td>220* (46)</td>
</tr>
<tr>
<td>R²</td>
<td>0.987</td>
<td>0.907</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at 10% error level with one-tailed t-test. Brackets below parameter estimates indicate heteroscedastic-consistent standard errors.
FIGURE 2: Rectangular System in the United States.
FIGURE 3: SPANISH AND MEXICAN LAND GRANTS IN CALIFORNIA.
Source: Hornbeck (1976).

FIGURE 4: THE US RECTANGULAR SURVEY AND THE SPANISH LAND GRANTS IN CALIFORNIA.
**Figure 5:** Patterns of Land Division in the Monterey Bay Area of California.
[Left panel shows map and right panel shows satellite image of the mapped area] Source: Hornbeck (1976) and Google Earth (2009).

**Figure 6:** Map of California with the Sample Townships Highlighted.
FIGURE 7: ADJACENT RS AND MB TOWNSHIPS FOR CASE STUDIES
APPENDIX

Data Sampling

California data from the 1860 Census of Agriculture were manually entered into excel from microfilm copies of the original records. We sampled only from those townships that were completely demarcated by either MB (i.e., rancho land) or RS (i.e., US survey after statehood). Table 2 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). We also calculated 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 we calculate Farmland value per acre as:

\[ \text{Farmland value per acre} = \frac{\text{Present cash value of farmland} + \text{Value of farming implements and machinery}}{\text{Total Acres}} \]

An alternative measure of farmland value would not include implement values, though the estimates from using this dependent variable are very similar to those presented in the paper. Below we show some summary statistics for the two measures of farmland values and note they are very close substitutes.

<table>
<thead>
<tr>
<th>Variable specification</th>
<th>Sample size</th>
<th>Mean</th>
<th>Stdev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm value per acre (with implement value)</td>
<td>427</td>
<td>25.89</td>
<td>57.09</td>
<td>0.09</td>
<td>1007</td>
</tr>
<tr>
<td>Farm value per acre (without implement value)</td>
<td>427</td>
<td>24.45</td>
<td>56.10</td>
<td>0.06</td>
<td>1000</td>
</tr>
</tbody>
</table>

Pearson Correlation Coefficients

\[ N = 427; \text{Prob} > |r| \text{under } H_0: \text{Rho}=0 \]

<table>
<thead>
<tr>
<th></th>
<th>Farm value per acre (with implement value)</th>
<th>Farm value per acre (without implement value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm value per acre (with implement value)</td>
<td>1.00</td>
<td>0.997 &lt; .0001</td>
</tr>
<tr>
<td>Farm value per acre (without implement value)</td>
<td>0.997 &lt; .0001</td>
<td>1.00</td>
</tr>
</tbody>
</table>
**Measuring topography by percent slope**

To measure the topography of the land or its **RUGGEDNESS**, we used Arc-GIS software to calculate the percent slope of the land, using 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 steeper the 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.

![Digital Elevation Model (DEM) of California](http://www.usgs.gov/state/state.asp?State=CA)

**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](http://www.usgs.gov/state/state.asp?State=CA).

![Study areas (Townships in blue outline) geo-referenced with the DEM.](image)

**Figure A.2:** Study areas (Townships in blue outline) geo-referenced with the DEM.
Farmland Quality

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) created in 2002. 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.

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 of Commissioners of the 1851 Land Commission, we used the ratio of un-patented acres of rancho land in townships, by referring to 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:

\[
\text{Unpatented Ratio} = \frac{(\text{Un-patented acres of rancho land in the Township by the year 1860})}{\text{Total area of Rancho land within the Township}}.
\]

County maps showing 19th Century Townships and Ranchos
Figures A.4- A.9 show the county maps we used to determine our sample of townships.

**Figure A.4:** Alameda County map showing administrative township boundaries, ranchos and rectangular system’s grid

**Figure A.5:** Fresno County map showing administrative township boundaries, ranchos and rectangular system’s grid
**Figure A.6:** Santa Clara County map showing administrative township boundaries, ranchos and rectangular system’s grid.

**Figure A.7:** Solano County map showing administrative township boundaries, ranchos and rectangular system’s grid.
**Figure A.8:** Sonoma County map showing administrative township boundaries, ranchos and rectangular system’s grid.

**Figure A.9:** Yolo County map showing administrative township boundaries, ranchos and rectangular system’s grid.