INDIANA UNIVERSITY

DEPARTMENT OF ECONOMICS

College of Arts and Sciences
Bloomington

Mark L. Waller
Professor and Acting Department Head
Department of Agricultural Economics
2124 TAMU
College Station, Texas 77843-2124

Dear Professor Waller and Members of the search committee

I'm writing to apply for the position of Assistant Professor in Agricultural Marketing & Quantitative Analysis at Texas A&M College of Agriculture and Life Sciences announced in Job Openings for Economists. This position aligns with my interests in resource and environmental economics, and policy analysis. I'm currently a Ph.D. candidate at Indiana University Bloomington in the Department of Economics and fully expect to complete my Ph.D. degree requirements by May 2020.

I am an applied microeconomist whose research centers on development economics, resource and environmental economics, urban economics and political economy. I am interested in the role of institutions on improving peoples' economic conditions, resource use and urban conditions. My research is question driven and I address it using theoretical foundations and rigorous research designs that allow me to estimate causal effects. In particular, during my Ph.D. I have been working on three lines of research: (i) the effect of institutions on development, (ii) the effect of institutions on resource and environmental issues, and (iii) urban planning and the effect of urban policies. My doctoral dissertation, entitled "Three Essays on Political Economy", was conducted under the direction of Professors Dean Lueck and Gustavo Torrens.

My first line of research investigates the effect of institutions on development. The goal is to understand how different institutional settings affect peoples' economic conditions. In my job market paper, I use farm-level data from the 1880 Agricultural Census for California and county level data from US Censuses of Agriculture from 1889 to 1959 to examine the effect of Spanish and Mexican land and water institutions on California farms' values, and irrigation. I document large losses in land values and irrigation from the inherited Mexican and Spanish land institutions. These findings highlight the importance of colonial institutions' details for economic development. In the same line of research, in another project I examine the role of individual land ownership on land certification programs' effectiveness in improving agricultural productivity. I study this in the context of the second Mexican land reform and Mexico's land certification program, PROCEDE, through which more than 20,000 agricultural communities were certified.

This line of research is naturally linked to political economy. In another paper with revision invited by *Kyklos*, I examine how party dominance affects elected politician's career path. It is substantively important to understand how institutions affect who gets to be in leadership positions because their characteristics influence economic development. In a companion project I examine the effect of politicians' career path on government performance, specifically on health and labor outcomes.

My second line of research concentrates on urban economics. The goal is to understand the economic factors that contribute to urban expansion and causally estimating the effect of urban policies on cities' economic outcomes. As part of the efforts to understand cities' expansion, I investigate the economic factors that determine the incorporation of rural land to urban centers' periphery. Regarding the effect of urban policies, in collaboration with Mexican researchers and with the support of the Lincoln Institute of Land Policy, we investigate the effect of large urban scale projects on real estate dynamics.

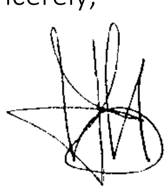
My third line of research focuses on the effect of institutions on resource and environmental outcomes. In the near future I plan to push forward this research line. In particular, I am currently working in two new ideas. In one project I'm trying to understand how Mexico's land certification program affected wildfire management, and how communal versus private property can explain the differences in management. In another project I explore how this certification program affected underground water use and the role of private versus communal ownership.

My research uses various econometric techniques for causal inference. I use quasi-experimental research designs, and I strive to incorporate the latest advances regarding those methods. I have extensive knowledge of Stata, Matlab and Python. Additionally, I have developed expertise in working with large datasets, and I also have expertise on web scraping using Python.

I consider teaching as an integral aspect of my future academic career. Since 2011, I have taught continuously, both as a teaching assistant and primary instructor of the course. I can teach several topics at both undergraduate and graduate levels: introductory and intermediate microeconomics, political economy, development economics, law and economics, urban economics, microeconometrics, and causal inference. Furthermore, I look forward to the opportunity to teach assigned classes and develop my own classes.

Given my overlapping research and teaching interests in resource and environmental and policy analysis, I believe I would be a good fit for the College of Agriculture and Life Sciences at Texas A&M. Included with my application, please find a copy of my curriculum vitae, and job market paper. I will gladly provide any other supporting materials upon request. I plan to attend the ASSA meeting in San Diego, California this January, and would be pleased to meet with you there or elsewhere at your convenience. I can be reached by phone at (812) 345-1223 or via e-mail at jramospa@indiana.edu. Thank you very much for your consideration.

Sincerely,



Julio A. Ramos-Pastrana
Email: jramospa@indiana.edu

Julio A. Ramos-Pastrana

Department of Economics | Indiana University | Bloomington, IN

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PLACEMENT DIRECTOR:	Bulent Guler	bguler@iu.edu	+1(812) 855-7791
PLACEMENT COORDINATOR	Brandie Roberts	econgrad@iu.edu	+1(812) 855-8453

EDUCATION

Ph.D. Economics, 2014-present (expected May 2020)
Indiana University, Bloomington, Indiana, US
Thesis Title: "Three Essays in Political Economy"

MA Economics, 2017
Indiana University, Bloomington, Indiana, US

MA Economics, 2012
El Colegio de México, Mexico City, Mexico

Specialty Certificate Course in Economic Theory, 2010
Universidad Nacional Autónoma de México, Mexico City, Mexico

BA Economics, 2009
Universidad Nacional Autónoma de México, Mexico City, Mexico

REFERENCES

Dean Lueck
Department of Economics
Indiana University
lueck@iu.edu

Gustavo Torrens
Department of Economics
Indiana University
gtorrens@iu.edu

Lee J. Alston
Department of Economics
Indiana University
ljalston@iu.edu

RESEARCH FIELDS

Development Economics, Resource and Environmental Economics, Urban Economics, and Political Economy

WORKING PAPERS

"The Legacy of Mexican Land and Water in California", jointly with Gary D. Libecap and Dean Lueck - Job Market Paper

"Who's Getting the Office? Party Dominance and Elected Politicians' Career Path" – revisions invited, *Kyklos*

WORK IN PROGRESS

"Land Certification and Agricultural Productivity in Mexico: the Role of Property Rights' Distribution"

Rules and Subdividing the Commons: Ejidos in Mexico

"Do Technocrats Save MoreInfant Lives than Politicians? The Impact of Governors' Career Path on Gubernatorial Performance", jointly with Claudia Avellaneda and Johabed Olvera

"Unintended Consequences of Fighting Drug Cartels: Maternal and Infant Mortality", jointly with Johabed Olvera

"Nudges Towards Less Salt Consumption and Maternal Health", jointly with Johabed Olvera

Julio A. Ramos-Pastrana

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"An Elephant in the Room: Early Impacts of Large Urban Projects on Real Estate Prices", jointly with Pablo T. Benlliure Bilbao, Marina E. Contreras-Saldaña, Maria E. Espinoza-Hernández, Alfonso Leyva-Garrido, Johabed G. Olvera, Pedro L. Ramos Pastrana, Adán J. Tellez-Ordaz and Eugene (Gene) Towle-Wachenheim

AWARDS, SCHOLARSHIPS AND FELLOWSHIPS

2019	**Hayek Fund for Scholars,** Institute for Humane Studies**, George Mason University**
2019	**Conference Funding Award**, Mercatus Center, **George Mason University**
2019	**Humane Studies Fellowship,** Institute for Humane Studies**, George Mason University**
2019	**Frank T. Bachmura Award for Outstanding Graduate Student in Development Economics or Comparative Systems,** Department of Economics**, Indiana University**
2019	**Full scholarship Ronald Coase Institute Workshop**
2018	**Adam Smith Fellowship**, Mercatus Center, **George Mason University**
2018	**Taulman A. Miller Award for Best International Student in Economics**, Department of Economics, **Indiana University**
2018, 2020	**Benjamin Friedman Travel Award,** Omicron Delta Epsilon
2017	**Daniel J. Duesterberg Award,** Department of Economics, **Indiana University**
2017-2018	**Ostrom Workshop Fellowship**, Ostrom Workshop, **Indiana University**
2016, 2019	Department Conference Funding Award, Department of Economics, **Indiana University**
2016, 2019	Fall College of Arts and Science Travel Award, **Indiana University**
2014-2019	Department of Economics Graduate Scholarship, **Indiana University**

GRANTS

2018	**Ostrom Workshop Research Award** "From Common to Private Property: Explaining the Evolution of Property Rights" PI ($5,000)
2018	**Tinker Field Research Grant** "From Common to Private Property: Explaining the Evolution of Property Rights" PI ($1,950)
2016	**Lincoln Institute of Land Policy.** "Analysis of the Impacts of the Proposed New International Airport for Mexico City on the Real Estate Market in the Metropolitan Area of the Valley of Mexico? (sic)" PI: Pablo T. Benlliure Bilbao ($20,000)

PRESENTATIONS

2020	ASSA Annual Meeting, Omicron Delta Epsilon Graduate Student Session (scheduled)
2019	IU Department of Economics, Ostrom Workshop, Ronald Coase Institute Workshop, El Colegio de México), IHS Fall Graduate Research Workshop, IU O'Neill (scheduled)
2018	ASSA Annual Meeting, Poster Session, ASSA Annual Meeting, Omicron Delta Epsilon Graduate Student Session, ASPS 2018 (Association of SPEA Ph.D. Students), The Life & Legacy of Douglass North. Celebrating the 25th Anniversary of North's Nobel Prize in Economics (Mercatus Center), IOEA 2018, SIOE 2018, 2018 APPAM International Conference, Symposium on Natural Resource Governance for Young Scholars (Ostrom Workshop)
2017	Western Economic Association International, 13th International Conference, ASPS 2017 (Association of SPEA Ph.D. Students), IU Department of Economics, Midwest Political Science Association, 75th Annual Conference, 13th Jordan River Economics Conference (IU Department of Economics), Ostrom Workshop

OTHER CONFERENCES ATTENDED

2019	PIEP (Ostrom Workshop)
2018	CLACS, Graduate Student Conference 2018 (discussant), PIEP (Ostrom Workshop), 2nd LSE-Stanford-U. de los Andes Conference on Long-Run Development in Latin America
2017	PIEP (Ostrom Workshop), American Political Science Association Annual Meeting

Julio A. Ramos-Pastrana

Department of Economics | Indiana University | Bloomington, IN

https://sites.google.com/site/julioalbertoramospastrana/ | jramospa@indiana.edu | +1(812)345-1223

RESEARCH EXPERIENCE

Fall 2018 Spring 2019 & Summer 2019 — **Research Assistant, Prof. Lee Alston**
Indiana University, Bloomington, Indiana, US

Fall 2016 & Spring 2017 — **Research Assistant, Prof. Dean Lueck**
Indiana University, Bloomington, Indiana, US

TEACHING EXPERIENCE

Fall 2018 & Fall 2019 — **Teaching Assistant, Theory of Prices and Markets I, (Microeconomics 1st year PhD sequence course)**
Indiana University, Bloomington, Indiana, US

Spring 2016 & Spring 2019 — **Teaching Assistant, Theory of Prices and Markets II, (Microeconomics 1st year PhD sequence course)**
Indiana University, Bloomington, Indiana, US

Fall 2015 — **Teaching Assistant, Introduction to Microeconomics**
Indiana University, Bloomington, Indiana, US

Fall 2014, Spring 2015 & Summer 2016 — **Graduate Assistant**
Indiana University, Bloomington, Indiana, US

2011 - 2014 — **Lecturer**
Universidad Nacional Autónoma de México, Mexico City, Mexico
Universidad Iberoamericana, Mexico City, Mexico

NON ACADEMIC EXPERIENCE

2013-2014 — **Director of Regulatory Studies, General Direction of Economic Regulation**
Instituto Federal de Telecomunicaciones (Telecommunications Regulator), Mexico City, Mexico

2013 — **Deputy Director, General Direction of Investigation of Monopolisation Practices**
Comisión Federal de Competencia Económica (Competition Commission), Mexico City, Mexico

2012 – 2013 — **Deputy Director, General Direction of Investigation of Monopolisation Practices**
Comisión Federal de Competencia (Competition Commission), Mexico City, Mexico

SHORT SCHOOLS

2019 — **Ronald Coase Institute Workshop**
Warsaw, Poland

2018 — **17th Institutional and Organizational Economics Academy (IOEA)**
Corsica, France

2011 — **2nd Summer School on Social Mobility (CEEY)**
Mexico City, Mexico

PROFESSIONAL AND ACADEMIC MEMBERSHIPS

American Economic Association
Association for Public Policy Analysis and Management
Omicron Delta Epsilon International Honor Society in Economics

COMPUTER SKILLS

Python, GIS, Fortran, Matlab, LaTeX, Stata, Microsoft Office

LANGUAGES

Spanish (Native), English (Fluent)

Report Results

Return

Student Unofficial Transcript
Indiana University Bloomington
Name : Ramos Pastrana,Julio Alberto
Student ID : 0003372193
SSN : XXX-XX-3233
Birthdate : 07-30-XXXX
Address : 2317 S Burberry Ln
Bloomington, IN 47401-4672
United States
Print Date : 11-13-2019
Request Nbr : 026585637

- - - - - Degrees Awarded - - - - -

Indiana University Degree
Indiana University Bloomington
University Graduate School
Master of Arts
Major: Economics
11-30-2017

- - - - - Beginning of Graduate Record - - - - -

Fall 2014 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	520	OPTIMIZATION THRY ECON ANALYS	3.00	B+
ECON-E	521	THEORY OF PRICES AND MARKETS 1	3.00	A-
ECON-E	522	MACROECONOMIC THEORY I	3.00	A
ECON-E	571	ECONOMETRICS I-STAT FOUNDATNS	3.00	A-

Semester:	IU GPA Hours:	12.00	GPA Points:	44.100
	Hours Earned:	12.00	GPA:	3.675
Cumulative:	IU GPA Hours:	12.00	GPA Points:	44.100
	Hours Earned:	12.00	GPA:	3.675

Spring 2015 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	502	TCHNG UNDERGRADUATE ECONOMICS	3.00	B+
ECON-E	572	ECONOM 2-REGRS/TIME SERIES	3.00	A-
ECON-E	621	THEORY OF PRICES AND MARKETS 2	3.00	A
ECON-E	622	MACROECONOMIC THEORY II	3.00	A-

Semester:	IU GPA Hours:	12.00	GPA Points:	44.100
	Hours Earned:	12.00	GPA:	3.675
Cumulative:	IU GPA Hours:	24.00	GPA Points:	88.200
	Hours Earned:	24.00	GPA:	3.675

Fall 2015 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	550	MONETARY THEORY & ORGANIZATION	3.00	A
ECON-E	626	GAME THEORY	3.00	A+
ECON-E	685	ADV INDUSTRIAL ORGANIZATION	3.00	A-
MATH-M	413	INTRODUCTION TO ANALYSIS 1	3.00	A-

Semester:	IU GPA Hours:	12.00	GPA Points:	46.200
	Hours Earned:	12.00	GPA:	3.850
Cumulative:	IU GPA Hours:	36.00	GPA Points:	134.400
	Hours Earned:	36.00	GPA:	3.733

Spring 2016 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	585	INDUST ORGANIZATN & CONTROL	3.00	A+
ECON-E	671	ECONOMET 3-NONLNEAR/SIMLT MDLS	3.00	A
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A+
		Course Topic(s): NETWORK FORMATION GAMES		
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): COMPUTATIONAL MACROECONOMICS		

Semester:	IU GPA Hours:	12.00	GPA Points:	48.000
	Hours Earned:	12.00	GPA:	4.000
Cumulative:	IU GPA Hours:	48.00	GPA Points:	182.400
	Hours Earned:	48.00	GPA:	3.800

Fall 2016 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	673	MICROECONOMETRICS	3.00	A
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): ADV MICROECONOMICS SEMINAR		
ECON-E	809	THESIS PH D	3.00	R
STAT-S	625	NONPARAMTRC THRY DATA ANALYSIS	3.00	A+

Semester:	IU GPA Hours:	9.00	GPA Points:	36.000
	Hours Earned:	9.00	GPA:	4.000
Cumulative:	IU GPA Hours:	57.00	GPA Points:	218.400
	Hours Earned:	57.00	GPA:	3.832

Spring 2017 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): ADVANCED MICRO THEORY		
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): ADVANCED ECONOMETRICS SEMINAR		
ECON-E	809	THESIS PH D	6.00	R

Semester:	IU GPA Hours:	6.00	GPA Points:	24.000
	Hours Earned:	6.00	GPA:	4.000
Cumulative:	IU GPA Hours:	63.00	GPA Points:	242.400
	Hours Earned:	63.00	GPA:	3.848

Summer 2017 Bloomington

Program : Economics -GrSch

Course		Title	Hrs	Grd
ECON-E	809	THESIS PH D	6.00	R

Semester:	IU GPA Hours:	0.00	GPA Points:	0.000
	Hours Earned:	0.00	GPA:	0.000
Cumulative:	IU GPA Hours:	63.00	GPA Points:	242.400
	Hours Earned:	63.00	GPA:	3.848

Fall 2017 Bloomington

Program : Economics -GrSch

Program : Economics -GrSch

Course		Title	Hrs	Grd
CSCI-B	565	DATA MINING	3.00	A
ECON-E	627	EXPERIMENTAL ECONOMICS	3.00	A-
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): ADV MICROECONOMICS SEMINAR		
ECON-E	724	SEMINAR IN ECONOMIC THEORY	3.00	A
		Course Topic(s): INSTITUTIONAL ANALYSIS		

```
Semester:   IU GPA Hours:     12.00  GPA Points:    47.100
            Hours Earned:     12.00  GPA:            3.925
Cumulative: IU GPA Hours:     75.00  GPA Points:   289.500
            Hours Earned:     75.00  GPA:            3.860
```

Spring 2018 Bloomington

```
Program  : Economics -GrSch
Course             Title                              Hrs Grd
ECON-E    724       SEMINAR IN ECONOMIC THEORY         3.00 A
     Course Topic(s): ADVANCED MICRO THEORY
ECON-E    809       THESIS PH D                        6.00 R
Semester:   IU GPA Hours:      3.00  GPA Points:    12.000
            Hours Earned:      3.00  GPA:            4.000
Cumulative: IU GPA Hours:     78.00  GPA Points:   301.500
            Hours Earned:     78.00  GPA:            3.865
```

Fall 2018 Bloomington

```
Program  : Economics -GrSch
Course             Title                              Hrs Grd
ECON-G    901       ADVANCED RESEARCH                  6.00 R
Semester:   IU GPA Hours:      0.00  GPA Points:     0.000
            Hours Earned:      0.00  GPA:            0.000
Cumulative: IU GPA Hours:     78.00  GPA Points:   301.500
            Hours Earned:     78.00  GPA:            3.865
```

Spring 2019 Bloomington

```
Program  : Economics -GrSch
Course             Title                              Hrs Grd
ECON-G    901       ADVANCED RESEARCH                  6.00 R
Semester:   IU GPA Hours:      0.00  GPA Points:     0.000
            Hours Earned:      0.00  GPA:            0.000
Cumulative: IU GPA Hours:     78.00  GPA Points:   301.500
            Hours Earned:     78.00  GPA:            3.865
```

Student Graduate Program Summary

```
GPA Hours:      78.00  Transfer/Test Hours Passed:     0.00
Hours Earned:   78.00  Points:         301.500  GPA:  3.865
```

Indiana University Graduate Summary

```
IU GPA Hours:   78.00  Transfer/Test Hours Passed:     0.00
Hours Earned:   78.00  Points:         301.500  GPA:  3.865
```

Academic Objective as of Last Enrollment

Economics -GrSch

Economics PhD

Return Go to Top

The Legacy of Mexican Land and Water in California*

Julio A. Ramos-Pastrana[1+], Gary Libecap[2], and Dean Lueck[1]

[1]Indiana University

[2]University of California Santa Barbara and NBER

November, 2019

Abstract: We analyze the effect of the inherited Spanish and Mexican land demarcation system in California on the state's early agricultural development. Land demarcation occurs in two dominant forms: metes and bounds (MB) and the rectangular system (RS). In MB, individuals specify land parcels. In RS, land is surveyed and demarcated prior to settlement and is organized in a uniform grid of square plots. In California large tracts of land granted during Spanish and Mexican rule of California called ranchos persisted once the region became part of the US. These ranchos did not form part of the US public land and thus inherited Spanish and Mexican MB demarcation, whereas the rest of the state became demarcated using the RS. As a result, these 2 systems coexist next to each other throughout California. We exploit this natural experiment and use farm-level data from the 1880 Agricultural Census for California and county level data from US Censuses of Agriculture from 1889 to 1959 to examine the effects of Spanish and Mexican land demarcation system on farms' shapes, values and irrigation. Our results indicate that land demarcation systems affected farms shapes and RS increased land values. In addition, after the New Deal policies that boosted irrigation, counties with a bigger share of RS increased their number of acres irrigated per irrigator more than counties with a large share of MB.

* We acknowledge good research assistance of Kate Burchenal. We thank the Mexican National Archives for allowing us to access primary sources about California under the Spanish and Mexican rule. We thank Pedro Ramos and Olga Pastrana for helping to gather the Mexican National Archives information. We thank the comments from presentations at the Ostrom Workshop, the 2018 ASSA meetings, The Life & Legacy of Douglass North, celebrating the 25th anniversary of North's Nobel Prize in economics, IOEA 2018, SIOE 2018, and the Symposium on Natural Resource Governance for Young Scholars. The usual disclaimer applies.

+ Corresponding author: jramospa@indiana.edu

I. INTRODUCTION

Colonial institutions have been found to explain countries' differences in contemporary economic outcomes. Seminal papers on this topic show colonialism affected modern income in the colonized countries (Acemoglu et al., 2001; Acemoglu, et al., 2002). Based on this literature, recent studies on this topic analyze specific historical institutions and their effects on economic outcomes (Banerjee and Iyer, 2005; Dell, 2010; Dell and Olken, 2018; Lowes and Montero, 2018; Valencia Caicedo, 2019).1 These studies have shown that the British land revenue collecting system in India (Banerjee and Iyer, 2005), the Anglo-Belgian rubber concessions in the north of the Congo Free State (Lowes and Montero 2018), and the Spanish forced mining labor system, *mita*, in Peru and Bolivia (Dell, 2010) negatively affected today's economic outcomes in these colonized countries, including education ,wealth, health (Lowes and Montero, 2018), household consumption, children's growth (Dell, 2010), agricultural investments and productivity (Banerjee and Iyer, 2005). On the other hand, Dell and Olken (2018) found positive effects of the Dutch Cultivation System in Java in terms of industrialization, infrastructure, education and wealth. Likewise, Jesuit missions in Argentina, Brazil and Paraguay provided human capital to colonized areas and have been found to increase today's educational attainment in these countries (Valencia Caicedo, 2019).

These studies, however, have mostly focused on extractive institutions and their long-run effects. Nonetheless, not all colonial institutions were extractive. For example, Bogart and Chaudary (2019) study investors' returns to Indian railways securities from 1869 to 1929 and conclude British railway policy was not extractive in India. 2 Additionally, these institutions had important short-term effects. Jedwab, et al., (2015) show the British railway system in Kenya determined cities locations back in the nineteenth century. Understanding short run effects of non-extractive historical institutions can broaden our understanding of the mechanisms driving colonial institutions' persistence on modern outcomes. Despite their importance, however, causal evidence on the short run effects of non-extractive colonial institutions is lacking.

1 Similarly, Bruhn and Gallego (2012) analyzes how specific colonial activities affected modern economic outcomes. Jedwab, Kerby and Moradi (2015) explore how colonial railways affected Kenya's spatial equilibrium and its persistence.
2 Bruhn and Gallego (2012) categorize colonial activities in 3 different groups: good (no exploitation of labor), ugly (exploitation of local labor), and bad (exploitation of imported labor or exploitation of local and imported labor).

This paper adds to this literature by analyzing the effect of a specific non-extractive historical institution – the land demarcation regime – on early California agricultural development. Two land demarcation regimes have dominated historically. Metes and Bounds (MB) is easily the most prevalent for both agricultural and urban land, and is found in parts of every continent, including Spain and Mexico. The Rectangular System (RS) was used extensively by the ancient Romans, and is now found in large regions of the US, 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 2012). 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 establishing these boundaries take little account of the spatial and temporal impacts of their choices. Demarcation is vague, imprecise and idiosyncratic. There are no uniform addresses, boundaries, shapes, sizes, or alignments. Under RS, 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.

California governing regimes under Spain, Mexico and the US resulted in MB and RS systems to coexist next to each other throughout the state. In addition to the traditional frontier institutions (missions, *pueblos* and *presidios*)[3], California's remoteness from New Spain economic center required Spanish advancement into the region to rely on large land grants called ranchos aimed to foster settlement in the area. The granting of ranchos continued during the Mexican rule of California to occupy the region. Under Spain only 17 ranchos were granted, however, under Mexico, over 700 grants were given. The granting of ranchos ended once the region became part of the US. Ranchos granted during the Spanish and Mexican rule of California, however, were not incorporated to US public lands. As a result, although once the region became part of the US land was demarcated under RS as required by the Land Ordinance of 1785, ranchos did not adopt it and remained being demarcated using MB as was

3 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 signi_cant settlements until the late 1700s (Morris 1994).

done under Spanish and Mexican rule. Eventually, ranchos were subdivided and sold to California's settlers under US rule.

California's history of colonization and settlement there provides a natural experiment to analyze the effect of Spanish and Mexican demarcation regime on agricultural development. Importantly, after California became part of the US, all land became subject to the same laws, allowing us to estimate the effect of Spanish and Mexican land demarcation, and not differences in underlying legal or property rights structure. Furthermore, the fact that ranchos were subdivided and sold to California settlers eliminate concerns about underlying differences in Hispanic origins of landowners instead of the demarcation regime.

We compare land values and irrigation development under these two different land demarcation regimes in early California. We show that compared to areas demarcated using the US system; the Spanish and Mexican land demarcation system systematically lowered farms' values and hindered the development of irrigation in the early years of the state.

The empirical analysis is divided in two parts. First, we use farm level data from the 1880 Agricultural Census for California to analyze the relationship between the land demarcation regime and farms' values. To identify farms' demarcation system we rely on historical land surveys from the nineteenth century. We take advantage of loose borders from the Spanish and Mexican grants demarcated using MB to estimate the impact of this land institution on land values and irrigation development. We document rancho's borders idiosyncratic definition using historical accounts and show that geographic characteristics such as land quality, precipitation, as well as farmers' characteristics are balanced across ranchos' borders. As a result, our empirical strategy consists in comparing farms located right on the border between RS and MB areas. Additionally, we rely on a very fine set of geographic fixed effects to strengthen the comparability between farms demarcated using MB and RS.

Our results indicate that on flat land the coordination gains from the RS surpassed the flexibility gains from MB, making RS farms' per acre value about 30 dollars greater than MB farms' value. More rugged terrain, however, made the flexibility gains from MB more valuable, decreasing the difference between RS and MB farms. We provide evidence that the mechanism driving these differences in farms' values is the extent of the RS network. When the size of the network is considered, differences in farms' values between RS and MB farms are no longer statistically significant, neither there are gains from rugged terrain in MB farms. Results are robust to a large battery of potential confounders, as well as different model specifications.

Second, we investigate the effect of land demarcation regime on irrigation levels. In doing so, we exploit variation in counties MB and RS areas, and take advantage of a positive shock to irrigation infrastructure: The New Deal irrigation policies. We hypothesize that counties with higher RS land shares would find it easier to coordinate and to develop irrigation as a result of the Bureau of Reclamation works. We use county level data from the US Censuses of Agriculture over 1889-1959 to test this hypothesis. Our identification strategy relies in a difference-in-differences model where we compare counties with a larger share of RS land to counties with a smaller share, before and after the New Deal irrigation policies. We show that counties with a larger proportion of MB land are a good counterfactual to counties with a smaller share.

Empirical estimates indicate that counties with a larger RS land share increased the number of acres irrigated per irrigator after the New Deal policies more than counties with a larger MB land share.

Overall our results indicate that Spanish and Mexican land institutions substantially transformed California's agricultural development in the early years for the state. We show that the RS system implemented by the US after California statehood generated large gains in farms' land values and the number of acres irrigated per irrigator. Taken together, our results imply large gains from coordination benefits arising from the network generated by the US demarcation system.

In addition to contributing to the literature on the effect of colonial institutions on economic development, this study contributes to the literature on the economics of land demarcation. Starting with the seminal paper from Libecap and Lueck (2011) that uses a natural experiment in nineteenth century Ohio to investigates the economic consequences of land demarcation, the study of land demarcation has received considerable attention. Libecap, Lueck and O'Grady (2011) study the choice of demarcation systems. Ellickson (2013) discusses the benefits from grid layouts in US cities' downtowns. O'Grady (2014) study how Manhattan's rectangular grid increased land values and land use density in the long run. Finally, Brady (2019) argues, from an historical point of view, that MB benefits were greater than economic studies have shown. This study provides further evidence on the substantial effects of RS demarcation by examining a different structure of MB demarcation, the one found in the Spanish and Mexican ranchos. Whereas MB in Ohio's Virginia Military District responded to individuals claiming the land, ranchos land subdivision responded to centralized decisions by the land grant owners.

The paper proceeds as follows. Section II presents California's land demarcation and ranchos history. Section III presents a theoretical framework from which testable implications are developed. Section IV introduces our data. Section V presents the analyzes for MB farms' shape. Section VI presents the empirical analysis of land demarcation and farms' values using nineteenth century microdata. Section VII presents the empirical analysis of land demarcation and irrigation development. Section VIII analyzes the costs from Mexican and Spanish demarcation in early California. Section IX concludes.

II. LAND DEMARCATION IN CALIFORNIA

Land demarcation in California was established under three successive regimes: Spain from 1521 to 1821, Mexico from 1822 to1848, and the US from 1848 to the present (Morris 1994). The system of MB was used by Spain and Mexico before the US introduced the RS, which then was applied to all remaining US land within California. It is this history that presents a natural experiment for our study of Spanish and Mexican land demarcation effects. Table 1 summarizes the key events and periods for land demarcation in California.

Table 1. Important Dates on California Land Demarcation

Date	Event
1521	New Spain established
1769	First Mission founded
1775	First rancho granted 1775-1821 17 ranchos granted
1821	Republic of Mexico established 1821-1845 Over 700 ranchos granted
1769-1848	MB is used in California
1848	Treaty of Guadalupe Hidalgo defines the terms of the US victory over
Mexico 1850	California becomes a state on September 9.
1851	California Land Act creates process for patenting rancho lands.
1851	Mt Diablo and San Bernadino principle meridians are established. 1851 -
Present	RS is used in California

Initially, land demarcation in California was carried out by Spain and Mexico using MB. The occupation of California began in the year 1768 with the enactment of the Royal Order to occupy Alta California. This was mainly done as a response from the Spanish Crown to the advancement of other foreign countries into the region, and to defend the ships in charge of carrying out the trade between New Spain and the Philippines from England and France (Ortega Soto, 1999). In 1821, Mexico gained its independence from Spain, and California became part of Mexico from 1821 to 1848. During all this time, land demarcation was done using an idiosyncratic system, akin to MB.

California became a US state in 1850, as a result land demarcation in the state started to be carried out using the RS system. MB demarcation in the United States ended with the Land Ordinance of 1785 (Hubbard 2009). The law required the federal public domain to be surveyed prior to settlement and that it followed 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 Ohio River and west of the Mississippi north of Texas.

The American rectangular system uses a network of meridians, baselines, townships, and ranges to demarcate land. 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. 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. In this manner, properties are positioned relative to one another in a standardized way. Figure 1 shows the basic features of RS in the US.

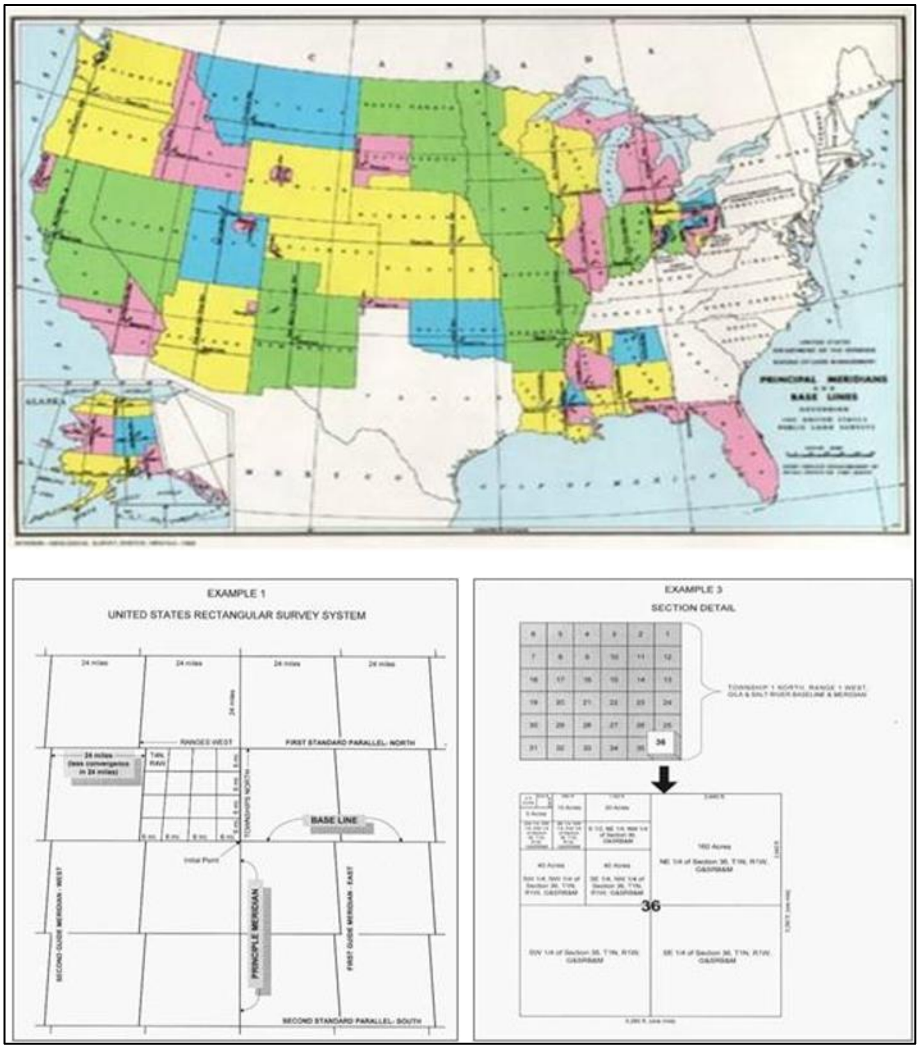

Figure 1. Rectangular system in the US. Source. Land Prints, Angels Camp, CA.

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 2002). 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.

The implementation of the principle meridians in California that govern the RS happened in the following way. 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 (Hubbard, 2009).

A. A Legacy of History: California's Ranchos

The Spanish strategy for the advancement and colonization of California relied on the development of three frontier institutions: missions, presidios and pueblos[4] (Ortega Soto, 1999; Ortega, 2008). These institutions were accompanied by ranchos, granted primarily to retired soldiers and located outside of missions, presidios and pueblos (Engstrand, 1985). See Figure 2 for a diagram depicting a typical layout of these land institutions.

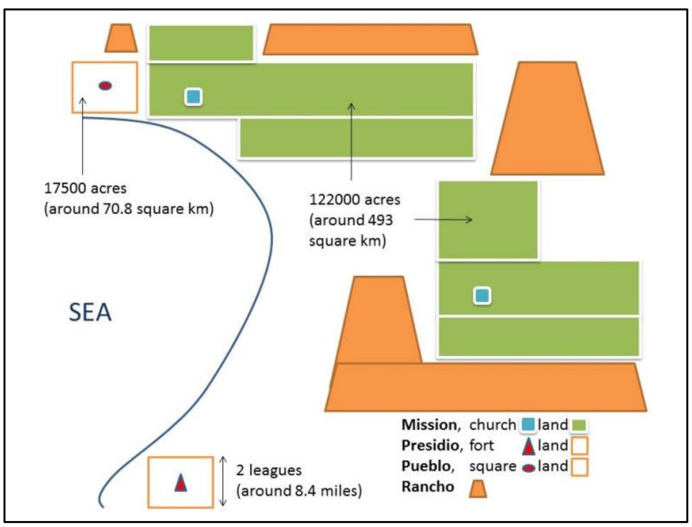

Figure 2. Diagram of California's Institutions prior to 1833.

4 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).

The requirements for receiving a rancho grant during the Spanish era were "the submission of a petition containing the name, religion, residence, occupation, family size and available livestock of the applicant. The petition also included a description of the vacant lands and a *diseño* or map of the property" (Engstrand, 1985). The first rancho was given in 1775 to a retired soldier (Engstrand, 1988). The second round of ranchos was granted until 1784: rancho San Rafael was given to José María Verdugo, a retired corporal; Manuel Nieto received rancho Los Nietos; and Juan José Domínguez received rancho San Pedro (Bancroft, 1884). During the Spanish rule of California only about 25 ranchos were granted, most of them along the coast (Engstrand, 1985; Harding, 1965). In 1784, when the first rancho was granted, there were nine missions, four presidios and two pueblos in California. At this time, only a few hundred Spaniards lived in the region and there were between 150,000 and 250,000 Indians. By the end of the Spanish era, 12 more missions were founded along with a third pueblo (Engstrand, 1988).

Mexico became independent in 1821 and the granting of ranchos continued. With the promulgation of the 1824 Mexican Constitution, the country adopted a more aggressive colonization process for California. The new laws fostered the establishment of both Mexicans and foreigners by promising security as well as tax exemptions (Engstrand, 1988; Castillo Negrete, 1959). The Mexican Colonization Law of 1824 was intended to foster the settlement of people in California, as well as its agricultural development. Once this new law was enacted, naturalized foreigners were able to receive land grants. These grants could not exceed 11 square leagues, and contained both pasture and farming lands (Hornbeck, 1978). The requirements to apply for the land grants "were essentially the same as during the Spanish period and involved a petition, description, design, and proof of occupation" (Engstrand, 1988). Firstly, a petition had to be filed with the governor, which included a sketch of the land, or *diseño*. The petition assured that no land had already been given under another grant and that the petitioner was Mexican, either by birth or by naturalization. Once this petition was filed, the governor transferred the documentation to the district where the land was located for verification. If such verification was favorable, the grant was approved and the governor signed a document, known as a *borrador*, to formalized it. The petition, *diseño*, and *borrador* formalized the grant. Together they formed an *expediente*, which was to be placed in the provincial archives.[5] In 1828 supplemental regulations concerned with the implementation of the Colonization Act of 1824 were enacted. "Together these statutes furnished the legal basis for all subsequent rancho grants that were to be made during Mexico's occupancy of California" (Hornbeck, 1978). From 1825 to 1831, the governor granted about 20 ranchos (Engstrand, 1988). The structure of property rights in these rancho lands was a constrained one. Rancho owners had to live on the land to keep the title, and these lands could "[…] not be transferred in mortmain" (Hornbeck, 1978). The first governor in the Mexican era granted 17 rancho grants (Engstrand, 1988).

The number of ranchos greatly increased after the secularization of the Missions. In 1833, the Mexican Congress ordered the secularization of the Missions, laying the groundwork for the forced removal of the Franciscans from the California missions in 1834 (Engstrand, 1988) and making available millions of acres of land for settlement (Hornbeck, 1978). The missions were meant to serve as the foundations for towns and the lands and livestock were supposed to be distributed between Indian families for farming and cattle raising (Engstrand, 1988). Private petitioners also could ask for mission lands to be subdivided amongst them by following the same procedure as in the 1824 and 1828 colonization laws (Glass Cleland, 1951). The result of this process was the rise of a great number of ranchos, and the acquisition of

5 This procedure did suffer small modifications in some cases; however, the general structure was the same (Glass Cleland, 1951)

cattle (Jackson, 1991). As Engstrand (1998) states, “during the 10-year period from 1835 to 1845, nearly 700 land concessions, many of which included the most fertile ex-mission tracts, were made to private claimants […].”

The granting of rancho lands ended with the Mexican American War and the cession of California, among other regions, from Mexico to the US.

B. A New Order: Land Settlement and California's Ranchos under US Rule

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 the Surveyor General in California to survey private land claims and federal lands (Robinson 1948). 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.

The rectangular system was implemented for all lands not previously demarcated under the Spanish and Mexican rule. RS demarcation proceeded from California principal meridians and worked outward, and around the ranchos, to cover the entire state.

In 1851, the California Land Act was enacted, which established a Board of Land Commissioners to decide on the ownership of the previously given Spanish and Mexican land grants (Hornbeck, 1979). 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). The confirmation process, however, was long and tedious, full of delays due to inaccurate boundaries and fraudulent claims. The presence of squatters on these rancho lands, as well as high legal fees, further complicated the matter (Engstrand, 1988).

Another difficulty arose from the destruction of public and private documents in government buildings during the Mexican-American War (Cortijo Ocaña and Cortijo Ocaña, 2002).

The provincial records of Spanish and Mexican governments, such as land deeds and sketch maps, were to be examined by the Board of Land Commissioners. 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 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 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). 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.

As time went by, these land grants were subdivided and sold. Taxes and the high legal fees incurred by rancho owners in the attempt to prove ownership of their land forced them to acquire enormous amounts of debt and mortgages. In many cases these loans could not be repaid, and thus the rancho owners lost their properties (Pitt, 1966). 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) were sub-divided using grid systems for demarcation, in areas such as Los Angeles, though these grids were not part of the RS.

> *By 1867 owners and land agents had begun to advertise the subdivision of large ranches for the benefit of settlers and colonists. One company alone offered 100,000 acres for such purposes. Former Governor John G. Downey advertised that 20,000 acres of choice agricultural land, situated sixteen miles from Los Angeles, would be subdivided into 50-acre tracts and sold on the installment plan for ten dollars an acre, with interest on deferred payments at the low rate of ten per cent per annum. A colony of a hundred families sought to purchase a portion of the Rancho la Laguna from Abel Stearns, and his agent informed him that settlers in large numbers were 'running over the ranchos,' looking for choice farm sites (Glass Cleland, 1951).*

Figure 3 presents all approved land grants throughout the state. Yellow areas represent rancho grants, while green areas depict RS lands.

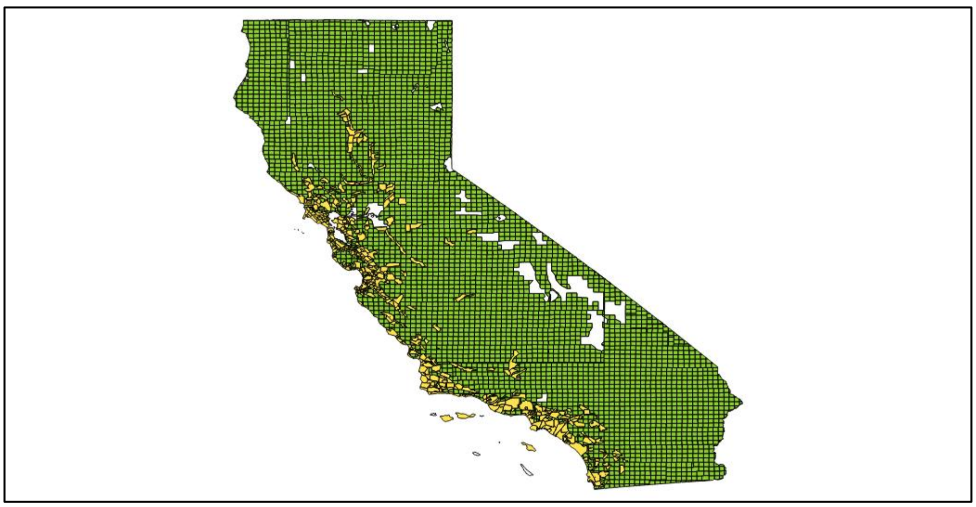

Figure 3. Land grants in California. Note. Yellow polygons corresponds to rancho grants in California, green areas correspond to the RS.

C. Ranchos' Loose Boundaries under Spanish and Mexican Rule

During Spanish and Mexican rule of California vague procedures were used to demarcate rancho boundaries. Plot descriptions during the Mexican and Spanish rule of California included references made to natural features some of which were not permanent- like trees, groves and streams. Rancho land was measured using a cord tied to two stakes, and two vaqueros were in charge of measuring under the supervision of the grant owner, some witnesses, and a magistrate. This method of surveying was not meant to be accurate; the grants were so large that actual boundaries had little importance. As a result, in some cases, even hundreds of acres did not have clear ownership. Land was so abundant at the time that rancho owners were not inclined to fight about it. For example, it was customary for rancho cattle to use neighboring lands since there was no fencing. Boundaries were defined by natural objects, many of which disappeared as time went by (Glass Cleland, 1951).

The vague procedure for the granting of lands during Spanish and Mexican California generated unclear boundaries and, in many cases, overlapping grants (Mawn, 1974). Imprecision was increased during Spanish and Mexican rule of California as there was an almost complete absence of professional surveyors (Robinson 1948). Figures 4 and 5 are some typical sketches presented to the Board of Land Commissioners. As can be seen, land grants frontiers were very vague, and used natural features to demarcate their borders.

The combination of loosely defined rancho boundaries and the introduction of the RS in California and later rancho subdivision, fostered farms with the same characteristics but different demarcation regimes to be located adjacent to each other around ranchos boundaries.[6]

D. A Natural Experiment in 19th Century California: Mexican and Spanish Land Grants

The natural experiment in land demarcation in California is the result of the differing approaches to the claiming and demarcation of land under the Spanish, Mexican and US rule. California's annexation to the US, combined with the fact that the land grants administered during the Spanish and Mexican rule did not form part of the RS, maintaining their original MB demarcation. As a result, both systems coexist next to each other throughout the state.

6 We exploit this peculiarity in our empirical strategy.

Further subdivision of the grants made farms with similar characteristics but different demarcation regime adjacent.

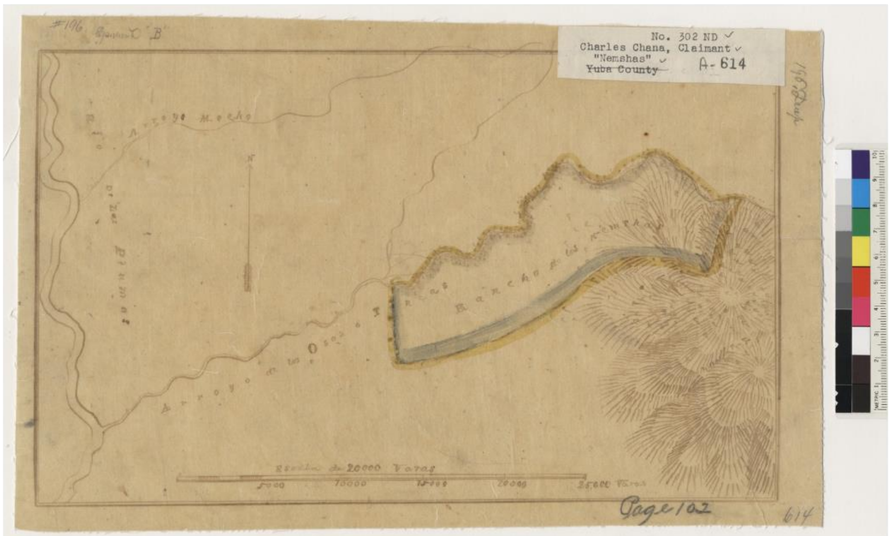

Figure 4. *Diseño* of *Rancho* Nemshas in Placer County. Source. Online Archive of California.

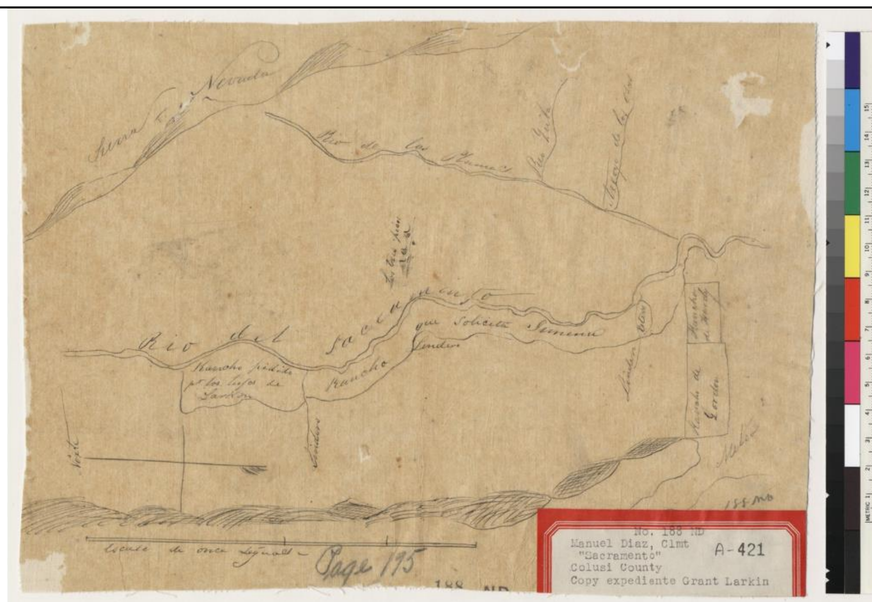

Figure 5. *Diseño* of *Rancho* Jimeno in Yolo County. Source. Online Archive of California.

III. Economics of Land Demarcation Systems

This section presents an economic framework to understand how MB and RS institutions affected parcel allocation, property rights, and land values and irrigation in the areas where each dominated. Accordingly, the framework presented here is designed to illustrate the options and tradeoffs facing by a social planner under each demarcation regime. We do not model the optimal selection of a particular system, but rather take those as given in order to focus on the decisions made by the planner under different demarcation constraints and assumptions. The framework suggests predictions that organize the empirical analysis.

In the model, the planner chooses the optimal allocation of land as squares, irregularly-shaped parcels, or a combination of them in order to maximize the net value of a large tract of land under varying topography.[7] The planner's decisions take place first in a setting where there are no transaction costs or network benefits—no enforcement costs, no information costs in determining the location and shape of parcels in trading, and no costs from the failure to align property boundaries for fencing and infrastructure investment. Further, the initial setup, survey, and administrative costs of the RS are sunk. The only costs are those of (i) deviating from squares under RS if plot customization becomes productively desirable due to rough terrain or (ii) of individual plot survey under MB because this is not supplied by the system. This setting generates a baseline from which we draw two predictions regarding plot shapes under the two regimes. We then allow for positive transaction costs and associated network benefits to indicate three additional predictions. We confront these five predictions in the empirical analysis, as well as calculate the losses from MB.

Our model allows us to examine the configuration of land parcels under both MB and RS under different topography. Rougher topography may make square parcels less productive

[7] We assume that the external boundary is enforced collectively or otherwise by a sovereign.

and parcel customization more attractive. Decentralized customization, however, may result in the loss of clear property boundaries and the network benefits of aligned, uniform parcels that provide for addressing, infrastructure investment along borders, and uniformity in plot descriptions for land markets. As a result the model illustrates the tradeoff between the property rights security and network benefits of RS and the benefits of personalized demarcation under MB.

A. Basic Assumptions and Framework

We make the following assumptions. The tract land of contains A acres and within this tract, there are potentially N farmers (claimants) who can be assigned to the land by the planner.[8] The net value of output for farmer i is $v_i(a_i, p_i, t_i)$where *a* is the area of the parcel (e.g., acres); p is the parcel perimeter (e.g., feet or miles); $t = (0,1)$ is an indicator of the land's topographical features (e.g., ruggedness or land quality).[9] We assume $v_a > 0, v_{aa} < 0, v_t < 0, v_{tt} < 0$. Diminishing marginal value in the size of the farm assures us that a single farm for the region is not optimal. The assumption regarding value and terrain indicates that more rugged topography will have lower productivity and higher surveying and policing costs.

To further simplify we assume there are just two types of parcels, squares and irregular parcels denoted by S and I respectively, and that the parcels are identical within each type $(a_i = a_j, p_i = j_j, for\ all\ i, j)$.[10] We also assume that each farm contains just one parcel, so there are no economies of collections of parcels. Though squares have many desirable productive properties, especially for relatively flat land, as terrain becomes more rugged

[8]To simplify we also assume the shape of the region A is assumed to be rectilinear.
[9]As in our empirical specification *t* is a slope measure where *t = 0* denotes flat land and *t = 1* denotes a cliff.
[10] We do not specify the shapes of the irregular parcels(a^I,p^I) but note that squares (a^S,p^S) imply $p^S = 4\sqrt{a^S}$. Since shapes are restricted under RS, *p* is fixed for each type of parcel.

deviation from square demarcation may be desirable.[11] We capture this feature by assuming [A1] $\partial v^S/\partial t \leq \partial v^I/\partial t \leq 0$. The planner chooses an allocation among the N farmers to maximize the surplus and we make the assumption that all land will be allocated.[12]

B. Demarcation under RS and MB: Baseline Model where TC = 0

Our baseline model assumes there are no transaction costs under either regime: There are no costs of transferring land, enforcing property rights, or cooperation in infrastructure investment. The only cost is in survey which differs between RS and MB.

RS Demarcation

Under RS the planner begins with a simultaneously assigned grid of square parcels whose previous costs of establishment, C^{RS}, are sunk. The planner can assign land to a farmer in squares at no cost, but it is possible to assign irregular shaped parcels only at an additional survey or switching cost of c per acre.[13] Irregular plots may be desired in response to variable terrain that increases the productive benefits of modifying a square.

Accordingly, to maximize the value of the land the planner allocates the land in the region between farmers with square parcels N^S and those with irregular parcels N^I :

$$\max_{N^S, N^I} V = \sum_{i=1}^{N^S} v_i^S(a_i, p_i, t_i) + \sum_{i=N^S+1}^{N^I} v_i^I(a_i, p_i, t_i) - c \sum_{i=N^S+1}^{N^I} a_i^I \quad (1)$$
$$s.t. A = \sum_{i=1}^{N^S} a_i^S + \sum_{i=N^S+1}^{N^I} a_i^S \ , \ \mathrm{N} = \mathrm{N^S} + \mathrm{N^I}$$

[11] We do not assume that the identical square demarcation used by the RS is the first-best optimal parcel shape, but squares have relatively low perimeter-to-area ratios (*p/a*) and squares also fill the interstitial space or gaps between parcels and are one of just three regular polygons – triangles, rectangles (squares), and hexagons – that can create patterns, with a common vertex and have no interstitial space (Dunham, 1994). Furthermore, squares like all rectilinear plots have production advantages for agriculture and urban use (Barnes 1935; Lee and Sallee 1974; Amiama, Bueno, and Alvarez 2008). Survey and fencing (enclosure) costs are lower for plots with fewer angles and longer straight boundaries (Johnson 1976).

[12] The assumption is strong because not all shapes can be packed to eliminate unclaimed areas. Relaxing this assumption means that there can be unclaimed areas ('gaps') but incorporating this into the model does not alter its implications.

[13] This simple per-acre survey cost ignores some complexities associated with surveying but captures the idea that there are costs associated with making adjustment from the grid. If it is prohibitively costly to create non-square parcels, then the planner simply choose the optimal number (and size) of identical farms within the RS grid.

The problem in (1) can be simplified by letting $A^I = \sum_{i=1}^{Ni} a_i^I$ and $A^S = \sum_{i=1}^{Ns} a_i^S$ where a^S and a^I are the (fixed) sizes for square and irregular parcels respectively. Uniformity among each parcel type implies $N^S = A^S/a^S$ and $N^I = A^I/a^I$ so the problem in (1) is simply the allocation of the region A into squares and irregular parcels.

The optimal solution to (1) must satisfy $v^I/\bar{a}^I \equiv v^S/\bar{a}^S + c$ where $\bar{a}^I(A,c,t)$ and $\bar{a}^S(A,c,t)$ are the optimal acreages in the two parcel types. This condition means the surplus maximizing allocation of the territory in square and irregular parcels requires that the per-acre value of a farm in squares is identical to the per-acre value of a farm in irregular parcels minus the per-acre adjustment/survey cost *c*.

The best allocation under RS of the region is then $\bar{N}^S$ identical squares of size $\bar{a}^S$ and $\bar{N}^I$ identical non-squares of size $\bar{a}^I$. Because irregular parcels have more relative value in rugged terrain [A1] the amount of land in irregular parcels is increasing in terrain ruggedness. So long as there is some land in the region for which that value increase exceeds the marginal survey cost, the optimal allocation implies a mix of parcel shapes under RS (i.e., $\bar{A}^I > 0$).

MB Demarcation

Under MB there is no predetermined grid that demarcates the parcel into identical squares, so the planner can initially simultaneously allocate the land among the *N* farmers into squares or some other irregular shape. There are individual plot survey costs, and these are c per acre, or cA for the region. The planners objective is only slightly different from (1) and is

$$\text{(2)} \qquad \begin{gathered} \max_{N^S, N^I} V = \sum_{i=1}^{N^S} v_i^S(a_i, p_i, t_i) + \sum_{i=N^S+1}^{N^I} v_i^I(a_i, p_i, t_i) - cA \\ s.t.\ A = \sum_{i=1}^{N^S} a_i^S + \sum_{i=N^S+1}^{N^I} a_i^S \ , \ \mathrm{N} = \mathrm{N^S} + \mathrm{N^I} \end{gathered}$$

The solution to (2) must satisfy $v^I/\tilde{a}^I \equiv v^S/\tilde{a}^S$ where $\tilde{a}^I(A, c, t)$ and $\tilde{a}^S(A, c, t)$ are acreages in the two parcel types. The optimal allocation of the region under MB is then $\widetilde{N}^S$ identical squares of size $\tilde{a}^S$ and $\widetilde{N}^I$ identical non-squares of size $\tilde{a}^I$.

Comparing Regimes when TC = 0

In this baseline setting of zero transaction costs a comparison emerges. Using assumptions about the effect of topography on the value of shapes [A1] and the optimality conditions in both RS and MB models, it follows that there will be more land in square parcels under RS than under MB.

Considering the peculiarities of our empirical setting, we can further characterize parcels' shape under MB. MB flexibility allows tailoring parcels to take advantage of natural features. California's semiarid climate makes water extremely valuable for agricultural purposes. Considering that ranchos had riparian water rights (i.e., plots adjacent to the water had the right to use the water), accommodating parcels to maximize the number of plots with access to water was extremely valuable for rancho owners looking to sell the plots from their subdivided lands. This can be achieved by demarcating plots in rectangles instead of squares (see figure 6).

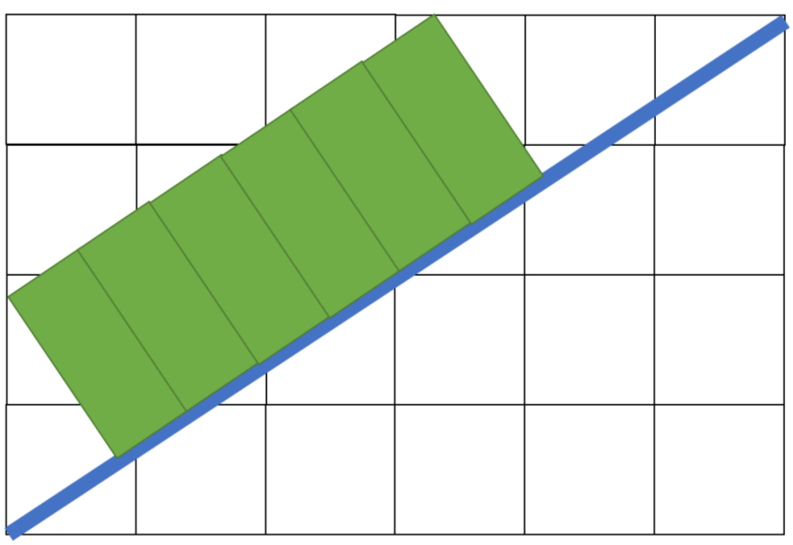

Figure 6. Land Demarcation Using Squares vs Rectangles.

As a result, we expect that in California areas demarcated using MB there will be rectangles next to the waterways.

Transaction Cost Implications

The zero transaction cost social planner's model, however, does not fully capture the differential costs and incentives under the two demarcation systems. While MB allows flexibility to tailor parcels to topography and thereby increase productivity, MB has several features may increase the costs of property rights definition, enforcement, trade, and investment: (i) there is no mechanism to coordinate alignment of individual parcels, (ii) parcels are bounded by impermanent and often vague features; and (iii) parcels are not uniform and are defined by local parameters.

RS demarcation with its fixed grid of aligned squares over a large area, addressed by latitude and longitude, however, resolves these issues. As such, the RS provides predefined, durable borders based on external factors, as well as network alignment and location benefits.[14]

As a result, we expect RS will generate the higher values in flat areas because of the network and location benefits. MB will generate as great or greater *ex post* flow of surplus than RS, however, in rougher terrain (t increases). The reason MB dominates is the square-parcel constraint under the RS. Some higher-valued irregular shapes are not chosen as they would be in MB because the extra value generated is less than the marginal deviation/survey costs. As ruggedness increases, the advantage of MB rises because the land is relatively more productive in irregular parcels.[15]

[14] 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). 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.

[15] Since $\partial v^S/\partial t < \partial v^I/\partial t < 0$ A^I is increasing in t. The region size (A) does not matter since there are no network benefits from RS demarcation.

Finally, the coordinated clarity of RS is also expected to have an impact on joint infrastructure investments. Contiguous linear borders should lower the cost of assembling rights of way along parcel boundaries. As a result, irrigation should be greater under the RS system. Furthermore, being able to coordinate farmers in areas with a larger proportion of RS demarcated land should be better equipped to take advantage of positive shocks in irrigation infrastructure, increasing their irrigation levels more than farmers in areas with a large MB area.

To guide the empirical analysis we offer the following predictions. The first two follow from the zero transaction costs setting, whereas the next two arise from the case where transaction costs are positive:

Prediction 1. The shape and alignment of parcels will vary more under metes and bounds than under the rectangular system and this parcel variation will increase in topography.

Prediction 2. Land in ranchos adjacent to waterways will be subdivided in rectangular plots, which will have the river orientation.

Prediction 3: There will be higher (per acre) land values under the rectangular system than under metes and bounds in flat land and this effect will be decreasing in terrain ruggedness so that in very rough terrain metes and bounds will provide as great or greater land values.

Prediction 4: There will be more acres irrigated per irrigator as the share of RS land in a county increases.

Prediction 5: There will be a greater increase in the number of acres irrigated per irrigator in counties with a bigger share of RS land after a positive irrigation shock.

IV. DATA

Our empirical estimates rely on data from several sources. To investigate the relationship between land demarcation regime and farms' values we use farm-level data from the 1880 US Agricultural Census for California and nineteenth century land surveys for California counties from David Rumsey's historical map collection, and the Library of Congress map collection. From the census we get several characteristics of each farm such as investment (acres improved, amount of money spent in fences, value of implements, etc.), farm value, type of crops, location at the township level, size, among others. Nonetheless, the census does not permit us to observe farms' exact location, and thus the type of land demarcation regime, our variable of interest. We use land surveys to overcome this difficulty. We matched farmers of the Census to the historical maps.[16] This enabled us to determine if a given farm was demarcated using MB or RS. Further, these maps helped us to document location characteristics such as adjacency to rivers, creeks, and railroads, and their location at the township-range level. We use the 1880 Agricultural Census for California because it was the closest to the historical maps, increasing our likelihood to match farms in the census to the historical land surveys. An advantage of using this census is that by 1880 90% of the ranchos had been patented, decreasing concerns regarding insecure property rights for MB farms because of squatters on ranchos. All ranchos in our sample had been patented by 1880. Our empirical analysis uses data from Sacramento, Solano, Sonoma, Sutter and Yolo counties[17] (see Figure 7).

To investigate the relationship between land demarcation and irrigation we use county level data from the US Censuses of Agriculture for the 1889-1959 period. Our empirical

16 We were not able to match each farmer from the Agricultural Census to the historical maps. We managed to match around 60\% of them.

17 We focus on these counties as all of them had historical land surveys available.

analysis uses the number of acres irrigated per irrigator, county area on farms and number of farms in the county.[18] We used the population censuses for the same time period to obtain county population.

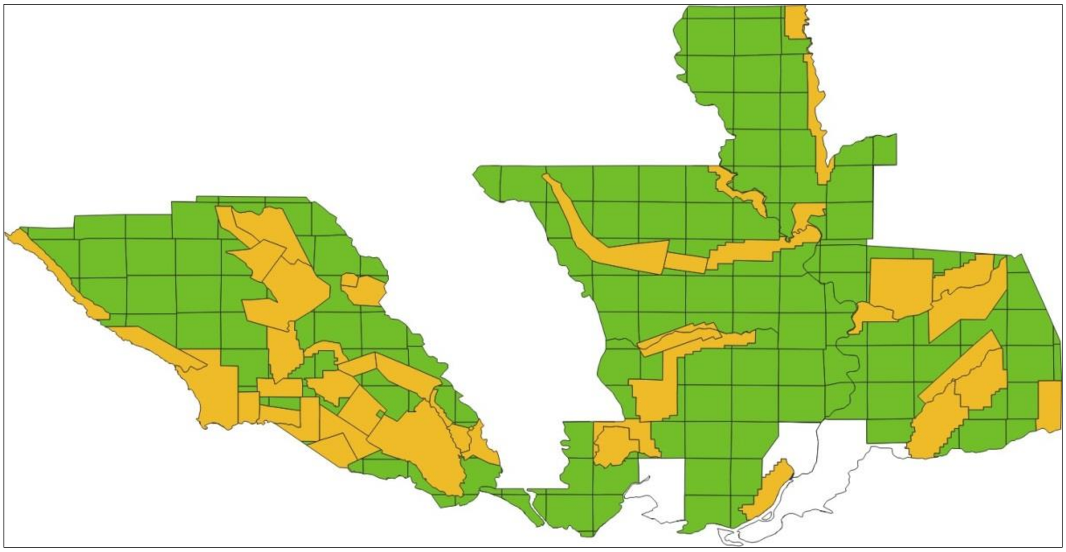

Figure 7. Sacramento, Solano, Sonoma, Sutter and Yolo counties. Note. Green areas correspond to the RS, yellow ares are land grants, and white areas are unsurveyed areas.

Geographic data comes from several sources. Land quality data comes from Schaetzl et al. (2012). We use the productivity index. The productivity index is an ordinal measure of productivity of a soil; it ranges from 0 to 19. The higher the number the more productive (USDA, 2018). We use historical precipitation data from PRISM, in particular, the precipitation level for 1895 as it is the closest to 1880. Ruggedness and elevation measures were constructed using Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) data.[19] We use 30 meters (1 arc second) data to calculate the slope. Finally, we use the population census to identify the 3 biggest cities in California in 1880 and calculate farms' distance to them. Given that we do not have georeferenced farms' data, all farms located in a given township range have the same value. Table 2 presents summary statistics for our sample.

18 Importantly, the census considers flooded lands as irrigated lands. Given that most farms on ranchos bordered rivers, they could irrigate their land by flooding it.

19 ASTER GDEM is a product of METI and NASA. The data was retrieved from USGS EarthExplorer (EE).

Table 2. Summary Statistics

Variable	Definition	Mean	SD	Min	Max
Farm Data					
Farm size	Total farm size (acres)	517.9	661.7	0	4,000
River	Farm with a side adjacent to a river	0.348	0.477	0	1
Railroad	Railroad tracks crossing the farm	0.105	0.306	0	1
Creek	Farm with a side adjacent to a creek	0.423	0.495	0	1
Value of production per acre	Estimated value of all farm productions (dollars)	7.498	9.261	0	100
Farm value per acre	Farmland value per acre (dollars)	35.84	52.10	0.571	500
Value of implements per acre	Value of implements and machinery per acre (dollars)	1.207	2.057	0	25
Value of livestock	Value of livestock per acre (dollars)	3.631	8.551	0	111.9
Cost of fence per Acres	Cost of building and repairing fences per Acre	0.182	0.421	0	4.688
Share Improved	Share of total farm land improved	0.849	0.284	0	1
Owner	Owner conducts the farm	0.925	0.263	0	1
Rents for fixed money rental	Renter conducts the farm for fixed money Rental	0.015	0.122	0	1
Rents for shares of Products	Renter conducts the farm for share of Products	0.060	0.237	0	1
Geographic Data					
Oakland	Township-range distance to Oakland (kms)	104.073	24.838	36.842	175.605
San Francisco	Township-range distance to San Francisco (kms)	108.760	26.790	45.911	182.834
Sacramento	Township-range distance to Sacramento (kms)	66.820	42.890	3.083	164.922
Precipitation	Average township-range precipitation in 1895	61.61	30.55	33.35	179.9
Ruggedness	Average township-range slope measure with value range [0,100], where 0 is flat Land	9.133	6.500	3.075	31.06
Productivity Index	Average township-range productivity in-Dex	9.762	1.779	0.0151	14.74
County Data					
Acres irrigated per Irrigator	Average number of acres irrigated per ir-rigator in the county	80.332	101.974	0	697.152
Farm area	Land in farms in the county (acres)	517792	403215.3	150	3313545
Farms	Number of all farms in the county	1859.05	2105.28	12	12653
Population	Total county population	103442.1	398629.5	241	6038771

V. DESCRIPTIVE EVIDENCE OF LAND DEMARCATION AND FARMS' SHAPE

In this section we investigate how farms' shape differed between the Mexican and Spanish ranchos and the US public lands. We present images from rancho grants in Sacramento (figure 8), and Sutter and Solano (figure 9) counties. As can be seen from these figures, we found support for predictions 1 and 2. As expected, there is a clear difference in farms' shape between RS and MB areas. In addition, it can be seen that rancho owners decided to subdivide their grants to maximize the number of plots adjacent to the water, which led to the use of rectangular shapes. Furthermore, it is noticeable that areas not adjacent to the rivers were demarcated using squares aligned to the RS. These patterns also hold for the other ranchos in the sample.

To formally analyze rancho farms' shape we used a regression framework.[20] According to our framework, there would be more variance in the number of sides in MB farms. As all farms demarcated using the RS have 4 sides, we analyze differences between RS and MB farms by estimating a regression of MB farms' deviation from 4 sides on ruggedness. We include as controls precipitation, the productivity index, the quadratic polynomial on latitude and longitude, a dummy indicating if the farm was adjacent to the river, and county fixed effects. Results indicate a positive correlation between ruggedness and MB farms deviation from 4 sides. Additionally, we estimate the probability of farms' having 4 sides on ruggedness. We found a negative correlation between ruggedness and MB farms' probability of having 4 sides.

Additionally, we calculated MB farms orientation. To do this, we compute the deviation (in degrees) of the largest side of MB farms adjacent to rivers, with respect to a horizontal line. Farms in the RS have a 0 degree deviation with respect to a horizontal line. We

20 Results are presented in the appendix.

expect MB farms adjacent to rivers to deviate from the horizontal line, as they will follow rivers orientation. 80 percent of MB farms adjacent to rivers deviate from the horizontal line.

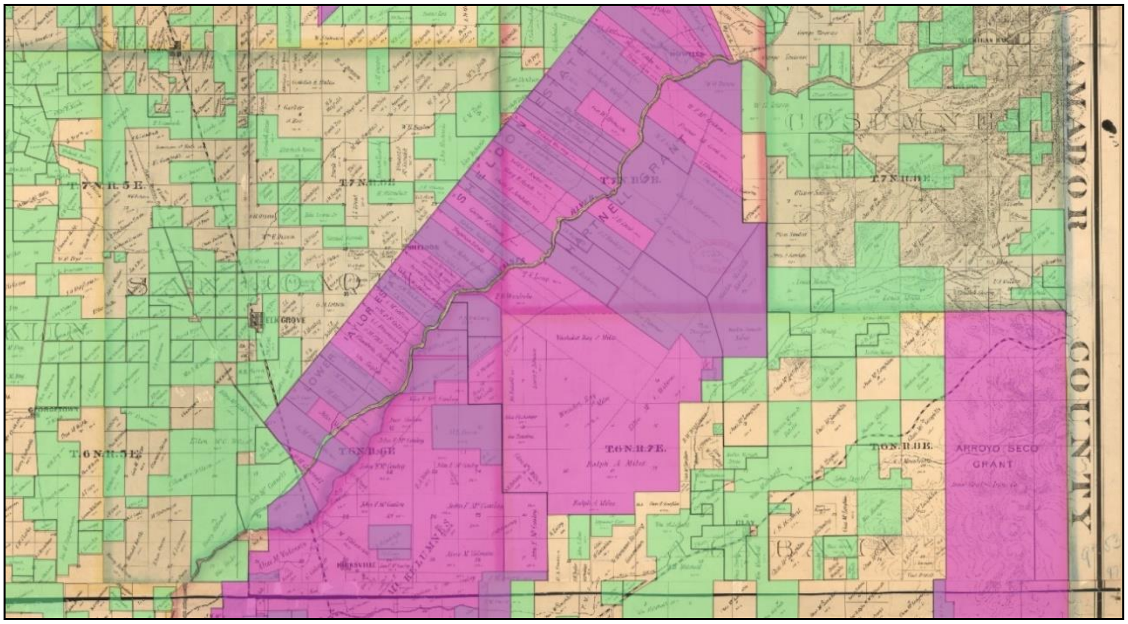

Figure 8. Rancho grants in Sacramento county. Note. Purple areas correspond to ranchos; beige areas are RS land; green polygons inside beige areas are farms matched to the 1880 census demarcated using RS; green polygons inside purple areas correspond to farms matched to the 1880 census located within rancho lands. Source. Library of Congress.

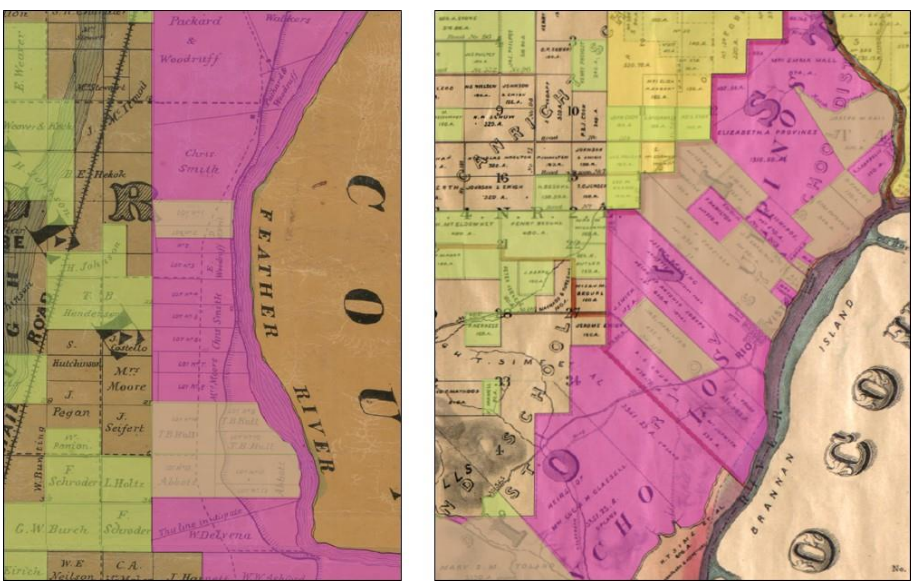

Figure 9. Rancho grants in Sutter and Solano counties. Note. Purple areas correspond to ranchos; beige areas are RS land; green polygons inside beige areas are farms matched to the 1880 census demarcated using RS; green polygons inside purple areas correspond to farms matched to the 1880 census located within rancho lands. Source. Library of Congress and David Rumsey's historical map collection.

VI. THE EFFECT OF LAND DEMARCATION ON FARMS' VALUES

A. Empirical Strategy

We use farm level data from the 1880 agricultural census to investigate the relationship between land demarcation regime and farms' values. In doing so, we estimate the following regression model:

$$V_{ij} = \theta RS_i + \gamma(RS_i * Ruggedness_j) + Rugg_j + River_i + \delta_t + \delta_{tr} + C'\beta + f(X_j, Y_j) + \varepsilon_i$$

where, V_{ij} is farm i in township-range j per acre value. RS_i is a dummy variable that takes the value of 1 if farm i is demarcated using RS and 0 otherwise. Our preferred specification controls for ruggedness and precipitation, both at the township-range level, and for a dummy variable taking the value of 1 if the farm is located next to a river. The model also includes an interaction between the RS dummy and ruggedness to investigate the gains from more rugged terrain. C is a matrix of control variables that includes a dummy variable that takes the value of 1 if the farmer had Hispanic name; distance to major cities (San Francisco, Oakland and Sacramento); dummy variables that takes the value of 1 if the farm is located next to a creek, or railroad tracks, respectively, and 0 otherwise; precipitation, and productivity index, all at the township range level. $f(X_j, Y_j)$ is a function of longitude X_j and latitude Y_j in township-range j. Finally, δ_t are township fixed effects, and δ_{tr} are township-range fixed effects.

Given that land values are a function of location, we include a very fine set of geographic fixed effects: township-range indicators. This amounts to restrict the comparison of RS versus MB demarcated border-farms to a very small area. Nonetheless, as some elements of location vary even in small areas, we include controls for access to rivers, adjacency to rivers, and precipitation.

Identification is this model comes from cross sectional variation in farms demarcated using the RS and MB. Since the land demarcation regime was defined previous to 1880, simultaneity is not a concern with respect to our estimation strategy. Thus, our main concern is the presence of omitted variable bias. This is a concern because ranchos' location was not random; ranchos were located close to pueblos and cities from the Spanish and Mexican eras, many of which evolved into large cities; next to waterways and in good agricultural zones. In particular, we would expect to encounter a downward bias for the following reasons: 1) larger distance from cities is positively correlated with the probability of a farm being demarcated using RS and negatively correlated with farms' per acre values; and 2) good land quality is negatively correlated with being a RS farms and is positively correlated with per acre value. Columns 1 to 3 in Table 3 present differences in means between the MB and RS farms in our sample. Notice that, in the full sample farms between RS and MB differ in geographic and census characteristics.

Table 3. Comparison of RS and MB farms in 1880

	Full			Adjacent		
	Mean			Mean		
Sample Characteristic	MB (1)	RS (2)	p-value (3)	MB (4)	RS (5)	p-value (6)
Geographic						
Productivity Index	9.547	10.398	0.0000	9.700	9.832	0.4207
Ruggedness	9.759	8.170	0.0000	8.228	10.153	0.0013
Precipitation	67.647	51.138	0.0000	59.717	63.741	0.1551
Oakland	95.448	105.998	0.0000	103.044	105.233	0.3417
San Francisco	97.788	113.125	0.0000	107.751	109.898	0.3875
Sacramento	80.039	50.381	0.0000	67.457	66.101	0.7333
Census						
Farm size	401.106	374.886	0.2261	622.278	400.2545	0.0003
Implements	1.926	1.299	0.0000	1.159	1.261	0.5960
Fences	0.371	0.287	0.2484	0.195	0.168	0.4852
Livestock	4.956	3.366	0.0000	4.216	2.974	0.1174
Vineyards	0.210	0.159	0.0032	0.206	0.214	0.8325
Wheat	0.566	0.620	0.0155	0.633	0.605	0.5269
Production	12.497	8.177	0.0000	8.147	6.770	0.1089
Wages	2.379	1.561	0.0001	1.565	1.277	0.1619
River	36.86%	16.32%	0.0000	0.5363	0.1363	0.0000
Observations	689	1623		248	220	

Two-sample t-test

$H_0 : MB - RS = 0$

Ranchos' loose demarcation process during the Mexican rule of California would suggest that farms located on ranchos' boundaries with the RS have the same characteristics on either side of the border. Thus, our estimation relies on comparing the sample of farms located on the boundaries of ranchos and the RS. We identify these farms using the historical land surveys. See figure 10 for our sample in Sacramento County.[21] Purple areas correspond to ranchos; beige areas are RS land; green polygons inside beige areas are farms matched to the 1880 census demarcated using RS; green polygons inside purple areas correspond to farms matched to the 1880 census located within rancho lands, yellow polygons correspond to our sample of rancho-RS border farms. As can be seen, our sample is composed of farms located on both sides of the RS-rancho borders. Columns 4 to 6 in table 3 present the difference in means for this sample of farms. As expected, the number of farms on either side is very close (248 in ranchos vs 220 in the RS), and most farms' characteristics are not statistically different between MB and RS farms, validating our research design. Only adjacency to rivers and ruggedness are statistically different between MB and RS farms, and we control for these two variables in our preferred specification.

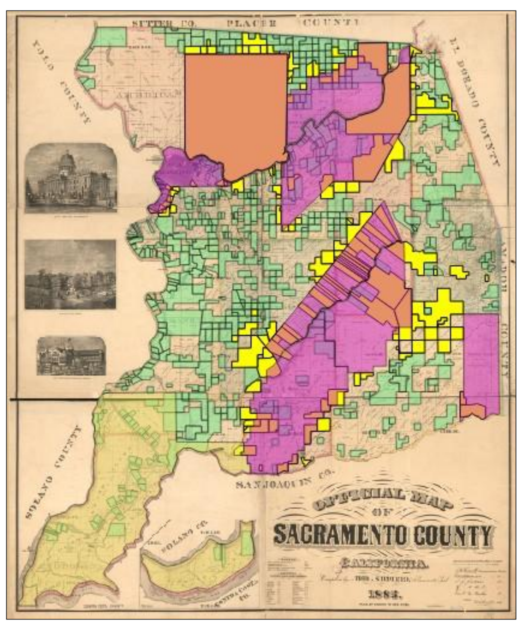

Figure 10. Sacramento county adjacent farms. Source. Library of Congress.

21 The Appendix contains the maps for the remaining counties.

B. Empirical Estimates

Estimates of the effect of RS are presented in table 4. Column 1 presents the baseline estimate. Our estimates provide support for our third prediction. In flat terrain, RS farms' per acre value was 30.2 dollars higher in comparison with MB farms. As farms township-range becomes more rugged, however, the difference in value decreases. A unit increase in the ruggedness measure decreases the difference between RS and MB farms in about 3.2 dollars, such that in areas with ruggedness greater than 9.4, MB farms would be more valuable than their counterparts.

The main result is not sensitive to a variety of robustness checks. Columns 2 to 8 show our estimates for land demarcation and its interaction with ruggedness are almost identical when several covariates are included in the regression. Column 2 includes a dummy variable that takes the value of 1 if the farm is adjacent to a creek and 0 otherwise. As ranchos located next to rivers, it is possible that some also located next to creeks to take advantage of the riparian water rights. Having access to water might increase per acre value, thus adjacency to creeks might bias our estimate downward. Results are robust to the inclusion of this control.

Column 3 includes as a control variable the distance to San Francisco. Ranchos were located around major cities in the Mexican era, which included San Francisco, and other pueblos that later evolved into major cities. Being close to San Francisco could affect per acre value as distance to the market would be smaller, this omitted variable could bias our estimate downward. Results change little when this control is included. Results are similar when controlling for distance to Oakland or Sacramento.

Columns 4 includes a measure for land quality, the productivity index. Ranchos located in areas with better land quality, and given that land quality is positively related to per acre values, this could bias our estimate downward. Again, results are robust to the inclusion of this control.

A potential confounder is farms on ranchos might be more likely to belong to people with Hispanic descend. Discrimination against people with Hispanic descend in the nineteenth century could reduce farms' per acre value, which could bias our estimate upward. To investigate this confounder we control for a dummy variable that takes the value of 1 if the farm owners has Hispanic name. As can be seen in column 5, inclusion of this control does not change our estimate.

Farms located on ranchos had to be paid in cash whereas farms on the RS could be homesteaded or paid in cash. If we think some farmers might locate on the RS or rancho due to wealth related reasons, this could bias our estimate as wealth might be correlated with land values. To investigate this possible confounder column 6 includes the proportion of farms paid in cash in the RS at the county level. Inclusion of this control does not affect our main estimate.

Column 7 includes a dummy variable that takes the value of 1 if railroad tracks touch the farm. It could be possible for railroad construction to differ between rancho and RS farms because of geographic characteristics. Having railroads crossing a farm could increase its per acre value by increasing its ability to access the market. Our results are robust to the inclusion of this control.

Finally, column 8 includes all controls. Our estimate is robust to all covariates being included simultaneously.

Table 4. Empirical Estimates for Farm Values per Acre.

	Dependent Variable: Value per Acre							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
RS	30.154**	29.498**	32.009**	29.486**	30.395**	30.196**	30.935**	29.918**
	(13.654)	(14.121)	(14.325)	(13.640)	(13.807)	(13.689)	(14.163)	(14.905)
RS*Ruggedness	-3.225**	-3.191*	-3.325**	-3.193**	-3.239*	-3.226**	-3.225*	-3.173*
	(1.599)	(1.669)	(1.163)	(1.565)	(1.610)	(1.602)	(1.605)	(1.643)
Ruggedness	1.010	0.981	1.050	0.990	1.160	1.011	1.070	1.171
	(1.559)	(1.617)	(1.538)	(1.535)	(1.590)	(1.561)	(1.545)	(1.605)
Creek		-6.278						-6.019
		(8.837)						(9.122)
dist(San Francisco)			0.001					-0.000
			(0.001)					(0.001)
Productivity Index				1.129				1.307
				(4.279)				(4.442)
Hispanic Name					90.888			90.558
					(73.768)			(75.142)
Prob(Cash)						-34.488		-12.707
						(53.328)		(78.736)
Railroads							14.366	15.068
							(13.885)	(14.308)
River	8.899	8.759	9.261	8.879	8.208	8.961	8.111	7.159
	(6.269)	(6.545)	(6.293)	(6.287)	(6.398)	(6.324)	(6.141)	(6.597)
Precipitation	0.760*	0.738*	0.777	0.799	0.719	0.759*	0.734	0.716
	(0.458)	(0.428)	(0.467)	(0.495)	(0.475)	(0.458)	(0.467)	(0.514)
Quadratic lat-lon	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Township FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Township-Range FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	467	467	467	467	467	467	467	466
R^2	0.3811	0.3828	0.3814	0.3812	0.3915	0.3820	0.3857	0.3980

Standard errors clustered at the township level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

C. Robustness to Specification

To investigate if model specification is driving the results, we modify the model and replace our quadratic polynomial in latitude and longitude for a linear, or a cubic one. Columns 2 and 3 of table 5 present the results for the linear and cubic polynomial, respectively. The estimates for RS and the interaction term RS and ruggedness do not vary much when these different polynomials are used.

Further, to investigate if per acre values' distribution is affecting the results we estimate the model using the logarithm of per acre values as dependent variable. Column 4 of table 5 shows the results hold when this transformation of the dependent variable is used.

Table 5. Robustness to Specification.

	DV: Value per Acre			DV: log(Value per Acre)
	(1)	(2)	(3)	(4)
RS	30.154**	32.456**	30.167**	0.496**
	(13.654)	(15.654)	(13.661)	(0.248)
RS*Ruggedness	-3.225**	-3.543*	-3.226**	-0.066**
	(1.599)	(1.927)	(1.601)	(0.030)
Ruggedness	0.010	1.341	1.012	-0.001
	(1.559)	(1.936)	(1.561)	(0.035)
River	8.899	10.211*	8.898	0.186
	(6.269)	(6.227)	(6.263)	(0.149)
Precipitation	0.760	0.919	0.762*	0.019***
	(0.458)	(0.463)	(0.459)	(0.007)
Quadratic lat-lon	Yes	No	No	Yes
Linear lat-lon	No	Yes	No	No
Cubic lat-lon	No	No	No	No
Township FE	Yes	Yes	Yes	Yes
Township-Range FE	Yes	Yes	Yes	Yes
Observations	467	467	467	467
R^2	0.3811	0.3747	0.3811	0.4974

Standard errors clustered at the township level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

D. Robustness to Rancho Title Uncertainty

Another potential concern is that ranchos might have suffered from squatters and land disputes. The discovery of gold in California provoked a huge influx of people into the state. In 1849, about 100,000 people arrived, primarily Americans. However, there was also migration from Mexico, South America and Europe; and by 1852 about 250,000 people migrated to California (Pitt, 1966). Because of the settlers' rush 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).[22]

Since squatters and land disputes are negatively correlated with per acre values, this uncertainty could bias our estimate upward. In other words, MB demarcated farms could have lower values irrespective of the demarcation system. Although by 1880 all the ranchos in our sample had been certified, diminishing concerns about rancho title uncertainty, to investigate if this is a possible source of bias we estimate the following model:

$$V_{ij} = \theta RS_i + \gamma(RS_i * Ruggedness_j) + \alpha(RS_i * Early\ Certified_j) + Rugg_j + River_i + \delta_t + \delta_{tr} + C'\beta + f(X_j, Y_j) + \varepsilon_i$$

where we include the interaction of RS with a dummy variable that takes the value of 1 if the rancho obtained its patent earlier than 1861, i.e., 20 years earlier than our sample, and 0 otherwise. If we think ranchos that obtained their patent sooner should have less squatters and more secure property rights than later certified ranchos, we should expect the difference between RS and MB farms to be smaller in early certified areas, i.e., $\alpha < 0$. Finding no heterogeneous effect between early and late certified ranchos suggests that rancho title-uncertainty is not biasing our results. Column 2 of table 6 shows there is no statistically significant difference in the estimate of RS demarcated land between early and late certified ranchos. We interpret this as evidence that ranchos' title uncertainty is not biasing our

22 This is especially problematic in Northern California. The enormous migration because of the Gold Rush had differentiated effects on rancho owners across the state. In the northern part, land uncertainty and related infestation of rancho lands by settlers, combined with the fact that rancho owners became victims of frauds by lawyers, resulted in many of the original owners of the northern ranchos losing their lands and having to move from their previously held grants (Pitt, 1966). On the other hand, lack of rain and mineral wealth allowed southern rancho owners to keep their lands (Pitt, 1966). Moreover, southern California's ranchos prospered after 1848 with the arrival of migrants. The huge increase in population expanded the demand for meat and pushed prices up, making the rancho owner's wealthy (Glass Cleland, 1951).

estimate.

Table 6: Robustness to Rancho Uncertainty.

	DV: Value per Acre	
	(1)	(2)
RS	30.154**	38.599***
	(13.654)	(14.891)
RS*Ruggedness	-3.225**	-2.879*
	(1.599)	(1.622)
RS*Early Certified		-16.596
		(10.840)
Ruggedness	1.010	0.288
	(1.559)	(1.669)
River	8.899	9.010
	(6.269)	(6.272)
Precipitation	0.760*	0.729*
	(0.458)	0.445
Quadratic lat-lon	Yes	Yes
Township FE	Yes	Yes
Township-Range FE	Yes	Yes
Observations	467	467
R^2	0.3691	0.3842

Standard errors clustered at the township level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

E. MECHANISM: NETWORK EFFECTS AND THE RS

Finally, according to our theoretical framework, RS should increase farms' per acre value since they belong to a network of farms demarcated in the same way, generating coordination benefits. To investigate if the size of the network can account for the differences between RS and MB demarcated farms, we make the following test. We augment our specification to include the proportion of RS demarcated land in the township range interacted with the RS indicator, and the triple interaction of the proportion of RS demarcated land, the RS indicator and the ruggedness measure. If the size of the network is responsible for the differences in per acre values between RS and MB demarcated farms, once controlling for the size of the network there should not be a statistically significant difference between RS and MB farms, nor there should be any gains from ruggedness in the MB farms. Column 2 of table 7 provides the results of this test. Once these new variables are included, the RS indicator and its interaction with ruggedness decrease substantially and are no longer significant. If the size of the network in the township-range is zero, although positive, the difference between RS and

MB farms is substantially smaller than the main estimate and is no longer statistically significant. Also, MB farms gains from ruggedness are close to zero and are no statistically significant. This suggests that the size of the network fully accounts for the differences between RS and MB demarcated land.

Table 7. Mechanism: Size of the Network.

	DV: Value per Acre	
	(1)	(2)
RS	30.154**	11.980
	(13.654)	(28.370)
RS*Ruggedness	-3.225**	-0.152
	(1.599)	(2.305)
RS*% RS		10.693
		(36.833)
RS*Ruggedness*% RS		-2.300
		(1.664)
Ruggedness	1.010	-0.651
	(1.559)	(2.105)
River	8.899	8.643
	(6.269)	(5.974)
Precipitation	0.760*	1.111*
	(0.458)	(0.575)
Quadratic lat-lon	Yes	Yes
Township FE	Yes	Yes
Township-Range FE	Yes	Yes
Observations	467	462
R^2	0.3691	0.3885

Standard errors clustered at the township level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VII. LAND DEMARCATION AND IRRIGATION

According to prediction 4, irrigators in a county with a larger RS land share should be more able to coordinate and, thus, they are expected to irrigate more acres than irrigators in counties with a large MB share. Further, they should be better equipped to take advantage of a positive irrigation shock (prediction 5). To investigate the latter hypothesis, our estimation strategy takes advantage of a positive shock in irrigation infrastructure: The New Deal (ND) irrigation related policies.

A. ND IRRIGATION POLICIES

The ND gave impulse to the Bureau of Reclamations. Several projects were authorized to create jobs and develop infrastructure (Bureau of Reclamations, 2018), and additional funding was given to the Bureau (Living the New Deal, 2018). During this period several dams and projects were developed (National Park Service, 2018). For example, the Central Valley project was initiated. Importantly, most land to be irrigated by this project was already private (Swain, 1970, Pisani, 2003). Given the large impulse to irrigation infrastructure, there are reasons to believe the ND policies affected the number of acres irrigated per irrigator. Figure 11 shows the average number of acres irrigated per irrigator in California for each census year. After the ND policies there is a sharp change in the trend of the number of acres irrigated per irrigator in the state.

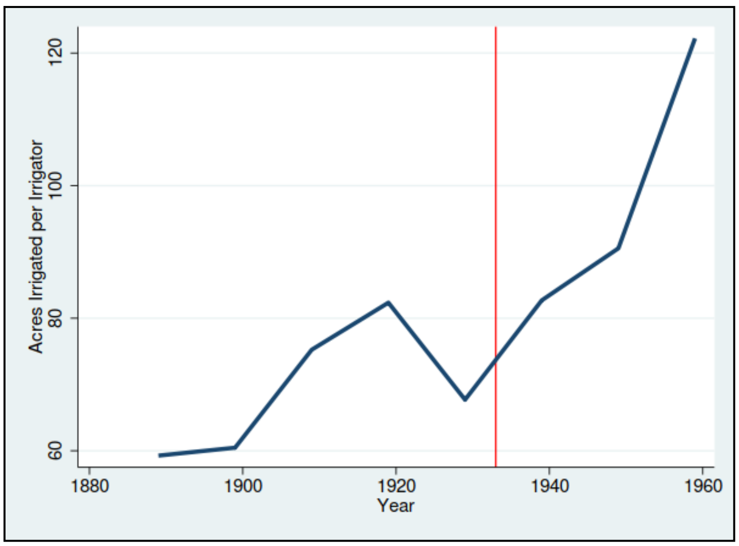

Figure 11. New Deal and Acres Irrigated per Irrigator in California.

B. Empirical Strategy

To investigate the relationship between land demarcation and irrigation outcomes, we exploit the fact that California's counties had different proportions of RS demarcated land, thus they could take advantage of the ND policies differently. Our theoretical frameworks suggests that farmers in counties with a larger proportion of RS demarcated land should be better equipped to take advantage of the positive shock in irrigation infrastructure provided by the ND policies. Thus, we expect a larger increase in the number of acres irrigated per irrigator after these policies came into effect in counties with a larger share of RS demarcated land.

To investigate this prediction we exploit panel data variation (over the period 1889-1959) and estimate a difference-in-differences (DiD) model that compares acres irrigated per irrigator in counties with high proportion of RS land to counties with a low proportion of RS land, before and after the ND irrigation policies. The estimated model is the following:

$$I_{ct} = \theta(\%RS_c * Post_t) + X'\beta + \delta_c + \delta_y + \varepsilon_{ct}$$

where, I_{ct} is the number of acres irrigated per irrigator in year t; $Post_t$ is an indicator variable that takes the value of 1 after 1929 and 0 otherwise; $\%RS_c$ measures the percentage of RS demarcated land in a given county, δ_c and δ_y are county and year fixed effects, respectively. Our control variables include county population, area of land in farms and number of farms.[23]

The identifying assumption of the DiD model is that the treatment and control groups had the same trends in irrigation outcomes prior to the treatment, and thus the latter is a useful counterfactual for the former. As a starting point, we plot the number of acres irrigated for all counties. Since the treatment is continuous, for ease of presentation we divide the counties in two groups: counties with high share of rancho land (more than 32% of its area)[24] and counties with a low share of rancho land (less than 32% of its area).

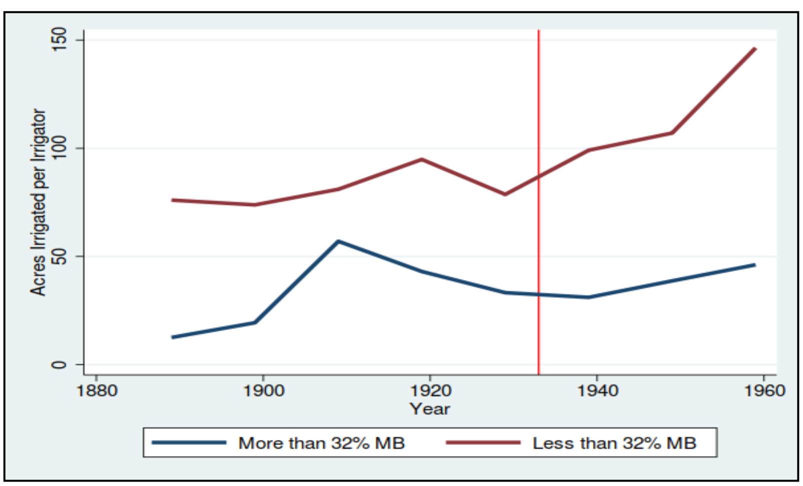

Figure 12. Pre New Deal Trends for Acres Irrigated per Irrigator at the County Level.

23 Area of land in farms and the number of farms were not available for the 1959 agricultural census.
24 75\% of the counties had less than 32\% of their area demarcated using MB.

Figure 12 suggests that counties with a large share of area demarcated using RS had the same pre-ND trends than those counties with a large share of their area demarcated using MB, validating the DiD design. We present a formal test of this assumption in a following subsection. Importantly, we can see in Figure 12 that in line with prediction 4 counties with a larger share of RS land have more acres irrigated per irrigator than counties with a smaller share. Furthermore, we can see a steeper increase in the number of acres irrigated per irrigator in the counties with a larger proportion of RS land after the ND policies. This is in line with prediction 5.

C. Empirical Estimates

As a starting point we pool the information for all counties and regress the number of acres irrigated per irrigator as a function of the share of RS demarcated land in the county. Column 1 presents the baseline estimate, it shows a strong correlation between the share of RS demarcated land in the county and the number of acres irrigated per irrigator. In particular, an increase in 10 percentage points in the share of RS demarcated land in the county increases the number of acres irrigated per irrigator in 9.3. This baseline estimation controls for total county population. This control is important since areas with more RS might have fewer population and thus fewer irrigators, mechanically increasing the value of the estimate. Column 2 allows for the possibility of differential trends between northern and southern California, results are robust to allowing for these differential time trends. Overall, these results provide support for prediction 4.

Table 8. Pooled OLS. Acres Irrigated per Irrigator

	DV: Acres Irrigated per Irrigator	
	(1)	(2)
% RS	93.535***	92.984***
	(30.944)	(31.333)
Population	-2.19e-05**	-2.19e-05**
	(9,02e-06)	(9.65e-06)
Year FE	Yes	Yes
Observations	458	458
R^2	0.0947	0.0976

Standard errors clustered at the county level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Once established there is a strong correlation between share of RS demarcated land and acres irrigated per irrigator, we aim to causally estimate the effect of land demarcation on acres irrigated per irrigator. Table 9 presents the DiD results for the number of acres irrigated per irrigator in each county.

Table 9. DiD. Acres Irrigated per Irrigator

	DV: Acres Irrigated per Irrigator	
	(1)	(2)
Post*% RS	37.621**	36.720**
	(15.706)	(15.836)
Population	-1.18e-05**	1.17e-05
	(1.61e-05)	(5.27e-06)
Year FE	Yes	Yes
County FE	Yes	Yes
N-S Trends	Yes	Yes
Observations	458	458
R^2	0.1656	0.1775

Standard errors clustered at the county level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

These results indicate that, in comparison to the counties with less proportion of RS land, the counties with a greater share of RS land had a larger increase in the number of acres per irrigator after the ND policies. In particular, after the ND policies, a 10 percentage points increase in the share of RS demarcated land in the county increased the number of acres irrigated per irrigator in 3.7. This result is in line with prediction 5. The coordination benefits from the RS helped farmers in counties with more RS land to pursue greater irrigation once the ND policies came into effect.

A key concern for our identification strategy is the possibility of differential time trends correlated with the share of RS land and the number of acres irrigated per irrigator. To address this concern, we allow for differential time trends between Northern and Southern California as they experienced different dynamics in terms of rancho land (see Section 2). Column 2 of table 10 presents the results including the region by year fixed effects. Results are robust to the inclusion of these trends.

Finally, since the DiD design does not control for time varying unobserved heterogeneity we explore whether some time varying omitted variable could be biasing our results. To address this issue we control for two potential confounders: area in farms and number of farms owners in the county. One could argue that counties with more area on farms might have more acres irrigated mechanically, thus correlating positively with the dependent variable. Similarly, counties with more farm owners might have more irrigators mechanically, having a negative correlation with the dependent variable. If area on farms and number of farms owners are correlated to the proportion of RS demarcated land in the county, this could bias our estimate. To investigate this possible bias, as a robustness test we control for both of these variables. Since these two variables are only available for the period 1889 to 1949, we proceed in the following way. First, we impute the value of 1949 to 1959, and present the results in column 2 of table 10. Second, we calculate the average growth rate for the period 1889 to 1949 and use it to calculate the value in 1959. Results are presented in column 3. Finally, we use only the original information, missing the year 1959. Column 4 presents the estimate.

Table 10: DiD. Acres Irrigated per Irrigator

		1889-1859		1889-1949
	(1)	(2)	(3)	(4)
Post*% RS	37.621**	38.339**	35.625**	30.640*
	(15.706)	(18.047)	(17.763)	(17.008)
Population	-1.18e-05**	-2.16e-06	4.07e-07	2.38e-06
	(1.61e-05)	(2.81e-06)	(2.93e-06)	(4.17e-06)
Farm owners		-0.009***	-0.008***	-0.008**
		(0.003)	(0.002)	(0.003)
Farm area		3.18e-06	1.3e-05	-2.17e-05
		(1.54e-05)	(1.07e-05)	(4.17e-06)
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
Observations	458	454	454	396
R^2	0.1656	0.1857	0.1888	0.0890

Standard errors clustered at the county level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10 shows the DiD estimate does not vary much when these control variables are included. Even when the sample is reduced (column 4), the increase in the number of acres irrigated per irrigator for areas with a larger proportion of RS land remains large and statistically significant.

D. ROBUSTNESS: EVENT STUDY ANALYSIS

A crucial question in a DiD design is whether counties that had a larger share of their area demarcated using RS would follow a similar trend to counties that had a smaller area in the absence of the ND irrigation policies. To formally test this assumption we perform an event study analysis. To do so we estimate the following model:

$$I_{ct} = \theta_t 1(year = t) * Post_t + X'\beta + \delta_c + \delta_y + \varepsilon_{ct}$$

where the treatment variables are a series of dummy variable that take the value of 1 for the counties with a larger share of RS demarcated land over the period 1889 to 1959, and 0 otherwise. The rest is defined as above. In this model, we test the difference between counties with high levels of RS land and counties with low levels of RS land each census year. The year 1929 is the baseline or excluded category. This event study provides a different coefficient for each census year leading up to and following the ND policies. The coefficients for the years before the ND irrigation policies allow to test differences in pre-policy trends. The post-policy coefficients measure how much the presence of the ND irrigation policy would be expected to affect irrigation outcomes each year after the ND irrigation policies started, relative to the year 1929.

Figure 13 presents the results of the event study. As can be seen from the figure, there is no statistically significant difference between counties with a large and a small share of their area demarcated using RS prior to the ND, validating our DiD strategy. Further, in line with our hypothesis, after the ND we see a sizeable and statistically significant increase in the number of acres irrigated per irrigator in those counties with a larger share of their area under the RS.

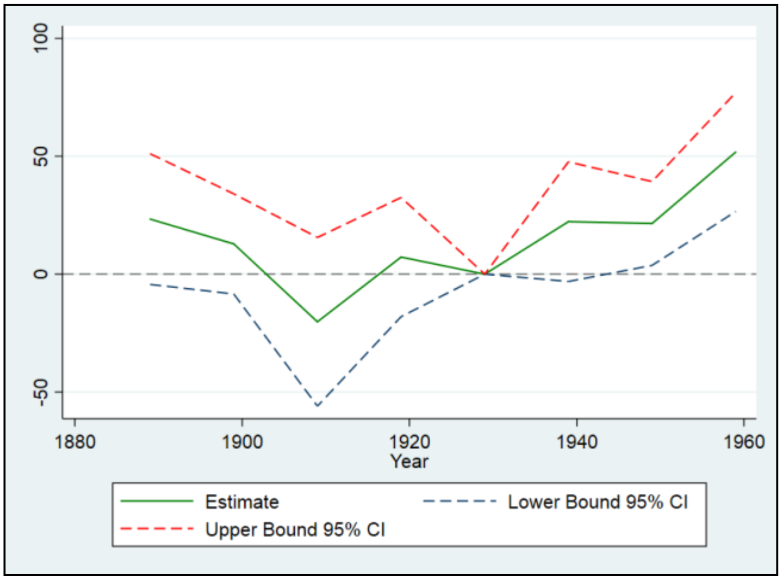

Figure 13. Event Study Analysis.

VIII. On the Costs of MB Demarcation

Our estimates can be used to analyze the costs or benefits from the Spanish/Mexican ranchos land demarcation on California's agricultural development. With respect to farms' values, our sample is composed of 37 ranchos, that amount to 961,589 hectares distributed through Sacramento, Solano, Yolo, Sonoma and Sutter counties. If all land in these counties were flat, ranchos MB demarcation would have meant a loss of 28,991,921 dollars in surplus for California farmers. Nonetheless, California terrain is far from flat. Figure 14 shows the distribution of ruggedness across the 37 ranchos in our sample.

As can be seen, a large proportion of the ranchos have a ruggedness level above the 9.4 threshold that makes MB more valuable than RS. In particular, 17 of the 37 ranchos in our sample have ruggedness above this threshold. This leaves 20 ranchos with a ruggedness level below 9.4, with a total area of 569,255 acres. Given the ruggedness level in these 20 ranchos, the loss for MB demarcation was 6,535,626 dollars.

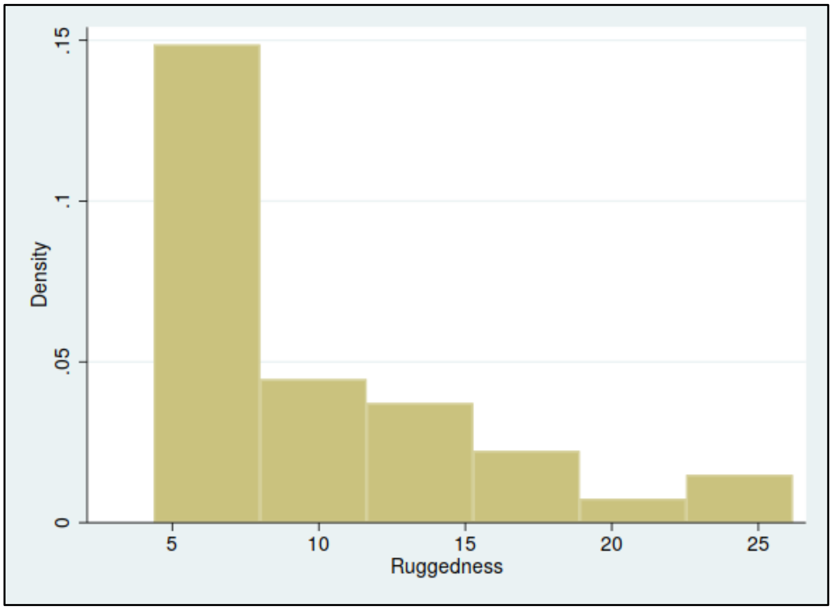

Figure 14. Ruggedness histogram

With respect to irrigation, our results indicate that on average 9.065 acres irrigated per irrigator were foregone after the ND policies because of MB demarcation. We use the Report on Agriculture by Irrigation in the Western Part of the United States to obtain the average value of irrigated land per acre in 1890 which equated 150 dollars. From the 1910 Agricultural Census, the average cost per acre irrigated in 1899 was 15.27. As a result, this would have implied a net loss of (150-15.27)*9.065=1,221 dollars per irrigator.

IX. Conclusion

Mexican and Spanish land demarcation institutions greatly differed from their American counterparts. In the Mexican and Spanish land demarcation systems individuals specify land parcels using natural features, whereas in the American system land is surveyed and demarcated prior to settlement and is organized in a uniform grid of square plots. The unique colonial history of California made both systems coexist next to each other throughout the state. We exploit this natural experiment in colonial land institutions to examine how the Spanish and Mexican land demarcation system affected early agricultural development in the state.

We show large gains from the American Rectangular System (RS) in comparison to the

Mexican and Spanish Metes and Bounds (MB) regime, in terms of farms' values and development of irrigation. Our results indicate that in flat terrain, the coordination benefits from RS overcome the flexibility gains from MB. As the terrain becomes more rugged, however, the flexibility gains from MB become more important, decreasing the difference in per acre value. We provide evidence that differences in farms' values result from the development of network of equally demarcated farms. In addition, our estimates from a DiD model suggest that RS land demarcation facilitated irrigation. Counties with a larger share of RS land increased their number of acres irrigated per irrigator after the New Deal policies that fostered irrigation more than counties with a smaller share of RS land.

Our findings highlight the importance of colonial institutions' details for economic development. Although Spain, Mexico and the US had private property and land was demarcated, we document large losses from the inherited land demarcation regime from Mexico and Spain. According to our estimates, over 6 million dollars in surplus were lost due to the Mexican and Spanish land demarcation regime, and on average farmers' lost over 1 thousand dollars in irrigated land value.

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X. APPENDIX

A. HISTORICAL LAND SURVEYS

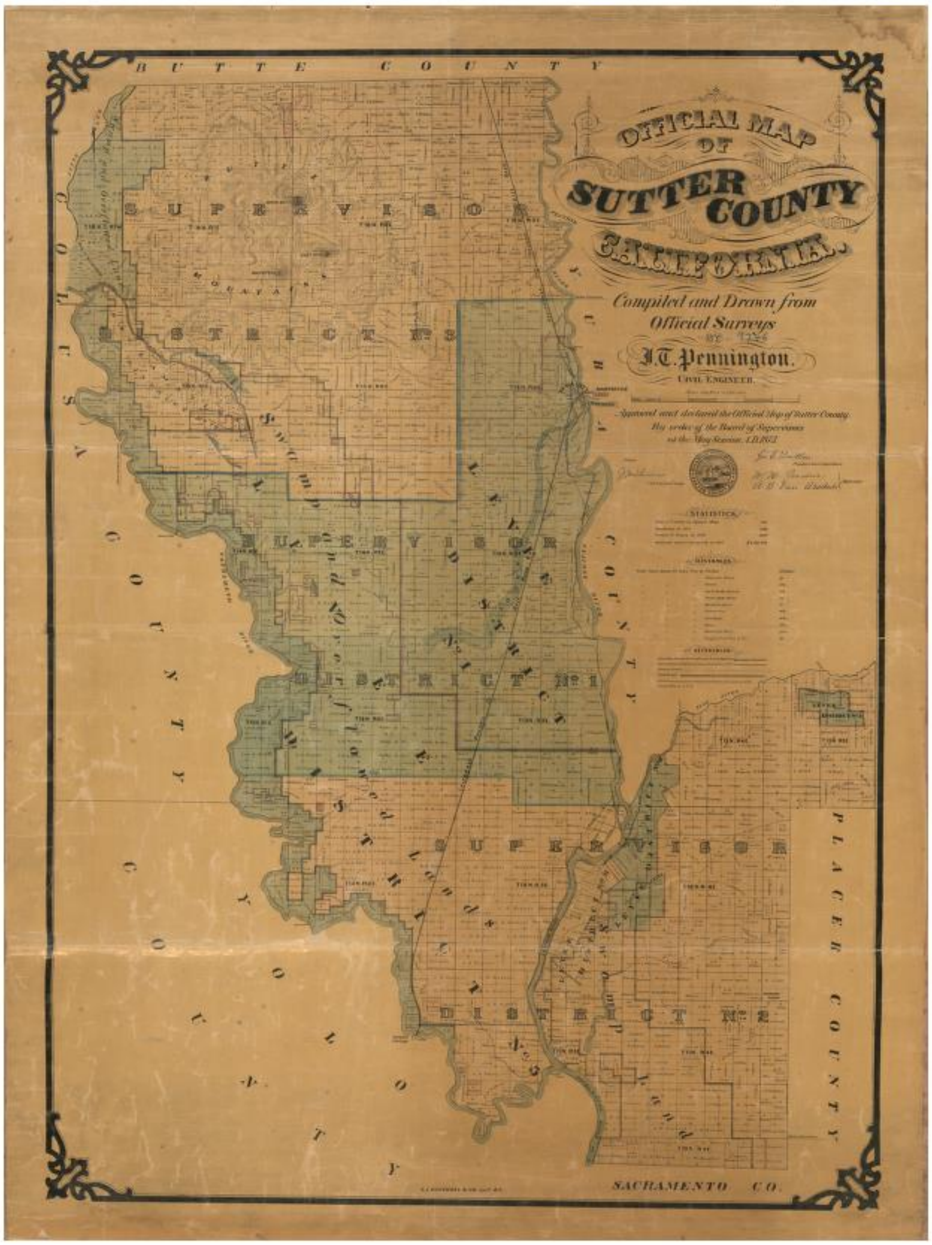

Figure A1. Map of Sutter County. Source.

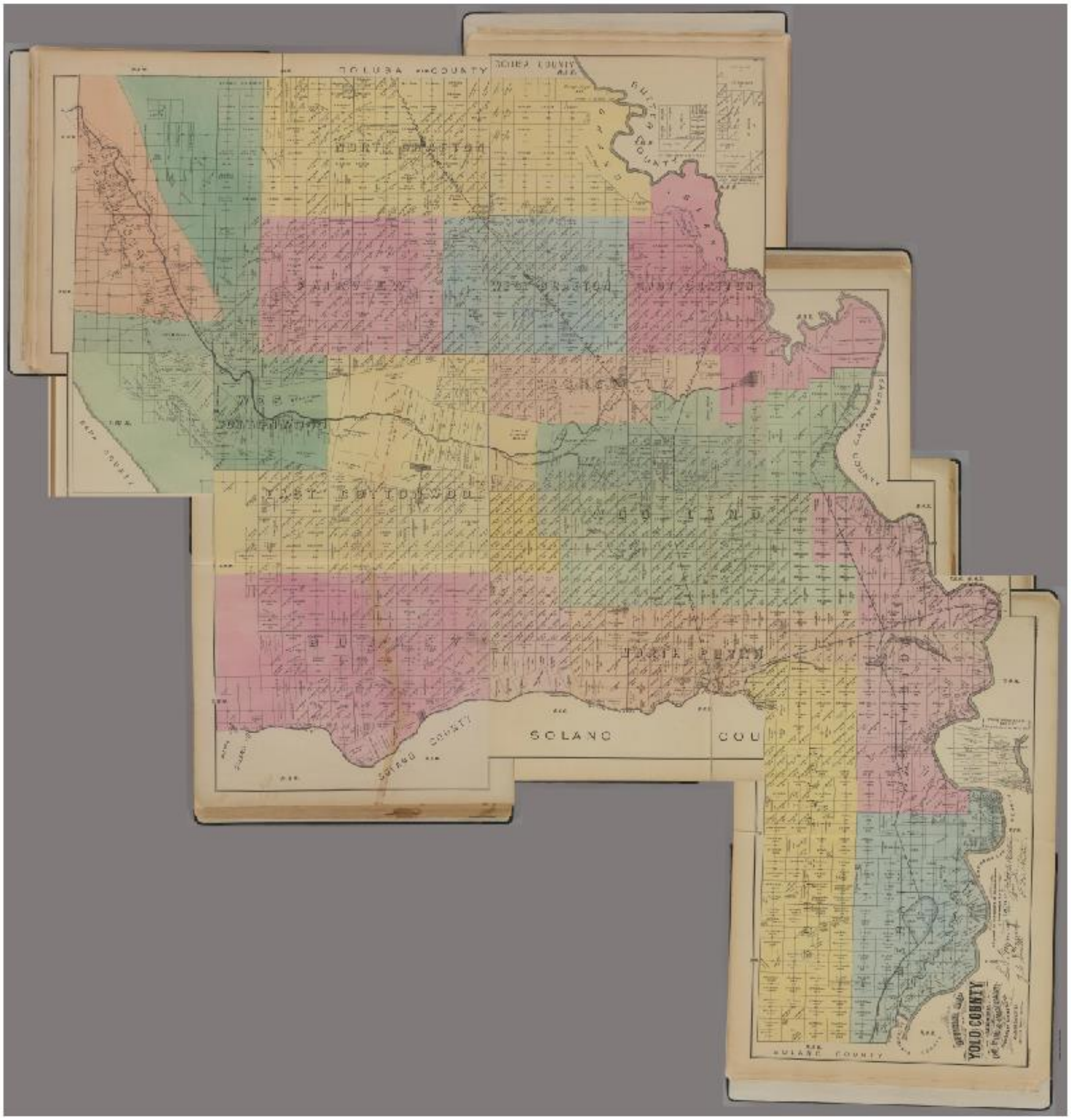

Figure A2. Map of Yolo County. Source.

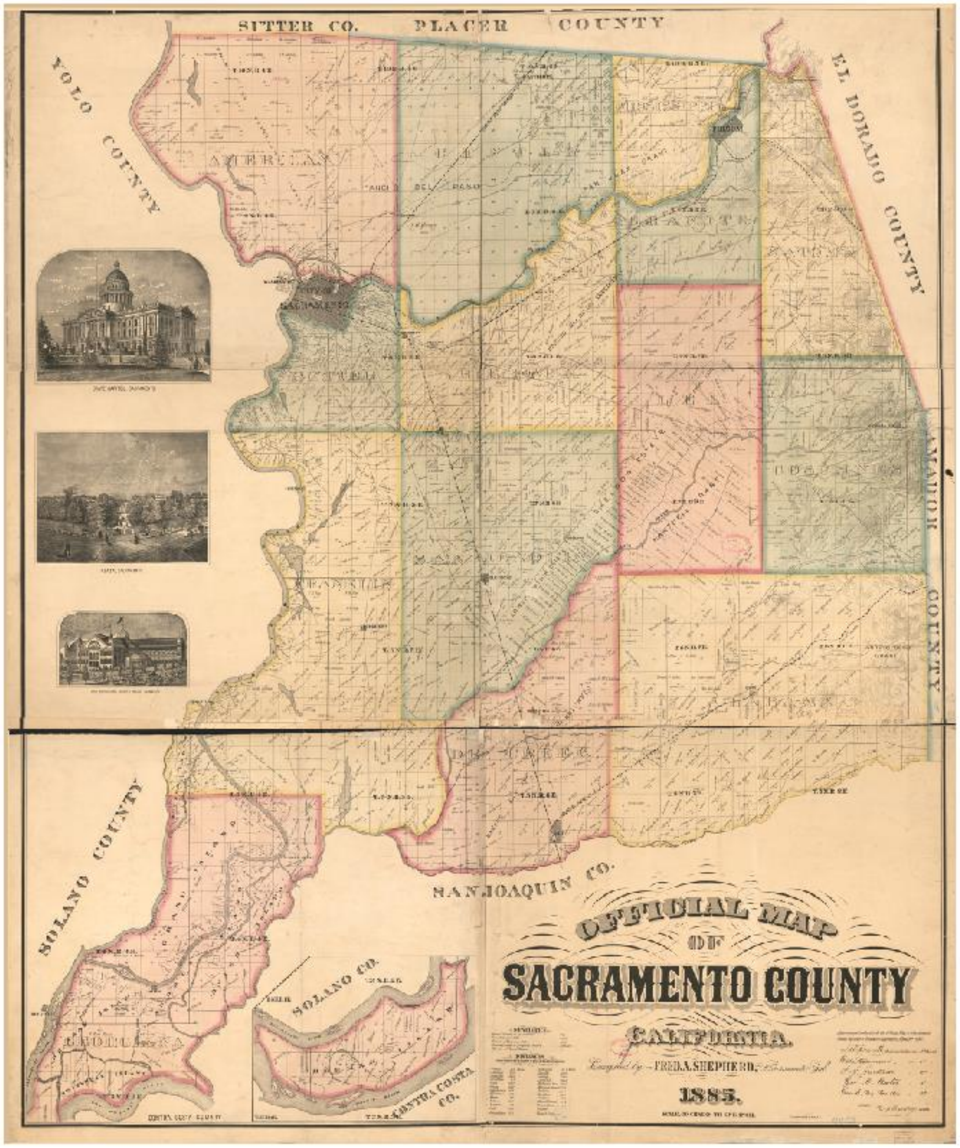

Figure A3. Map of Sacramento County. Source.

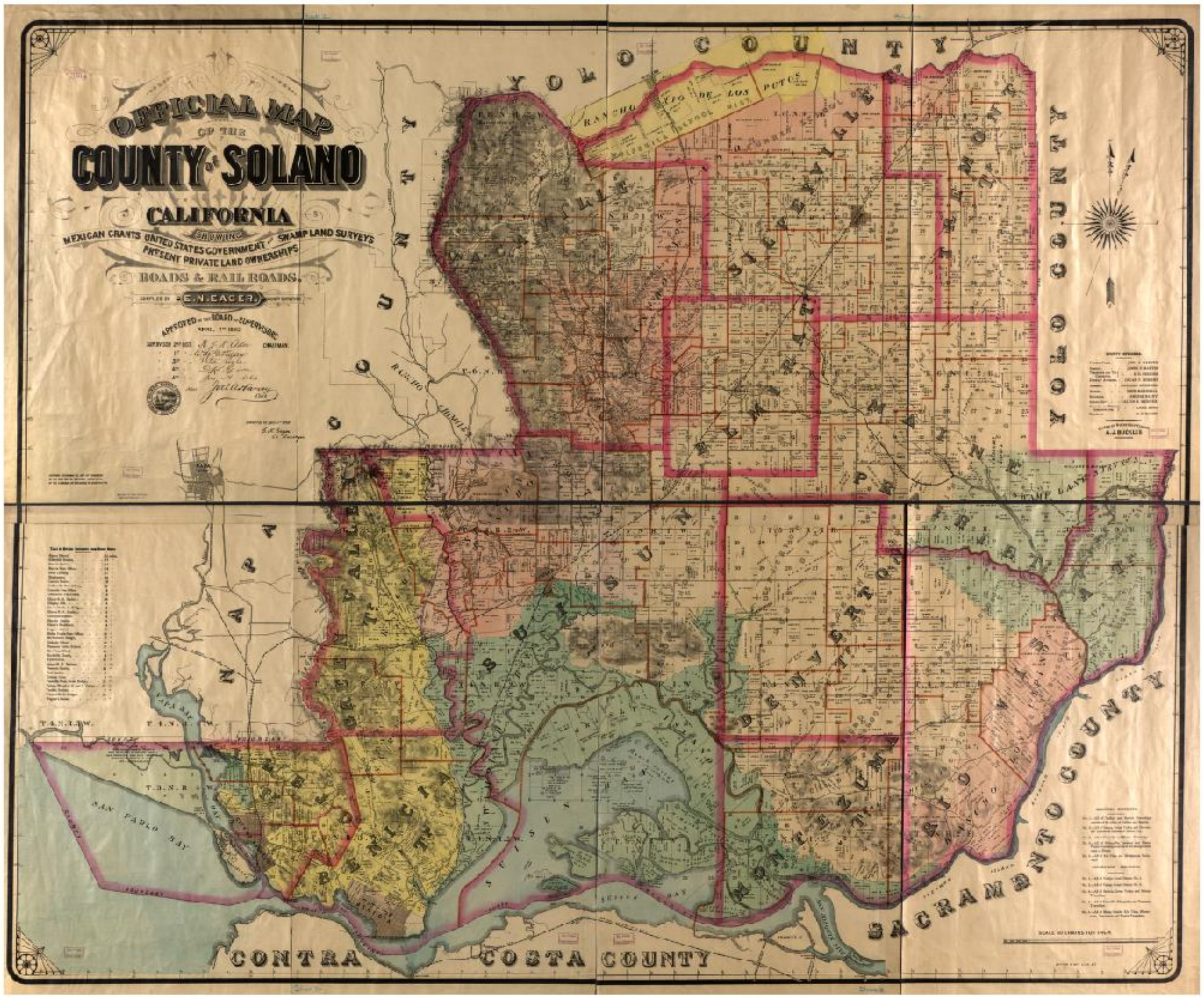

Figure A4. Map of Solano County. Source.

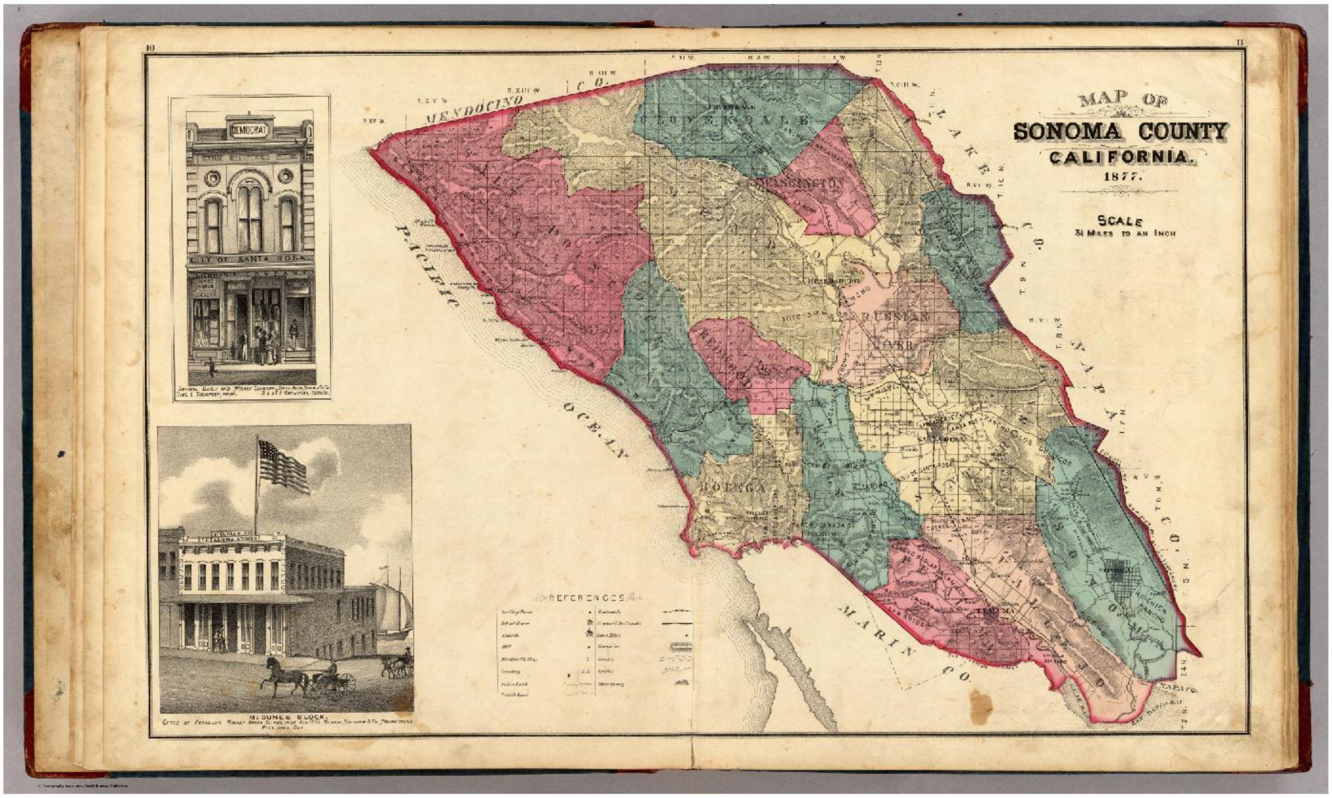

Figure A5. Map of Sonoma County. Source.