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Large-Scale Institutional Changes: Land Demarcation in the British Empire

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Abstract

We examine adoption of land demarcation in the British Empire during the seventeenth through nineteenth centuries. We develop a model and test its implications against data from temperate British colonies in North America, Australia, and New Zealand. Three arrangements were implemented: individualized, idiosyncratic metes and bounds; a centralized, uniform rectangular system; and a centralized, nonuniform demarcation system. The choice of arrangement is determined using demarcation, topographical, and soil quality data sets with qualitative, historical information. We find that centralized systems provide coordination benefits, but adoption is less likely when implementation is slow and controlling settlement is costly. In centralized systems, we find that uniform rectangular demarcation lowers transaction costs, but its rigid structure is costly in rugged terrain, and alternatives are adopted.

> [I]n the absence of transaction costs, it does not matter what the law is, since people can always negotiate without cost to acquire, subdivide, and combine rights whenever this would increase the value of production. In such a world the institutions which make up the economic system have neither substance nor purpose. [Coase 1988, p. 14]

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> I will only repeat the expression of my confident trust that you have sacrificed everything else to the one essential thing—the survey, the survey, the survey. [Wakefield 1868, p. 290]

1. Introduction

Institutions can change in dramatic fashion. For example, after conquest, the victor can force the vanquished population to accept its language, law, currency, economic organizations, and form of government. In so doing, the victor expands its institutional reach.[1] Among these new institutions are those that govern land, perhaps the most fundamental of resources. A conquering regime can decide how property rights to land will be demarcated and assigned. Once implemented—and absent another dramatic change—these institutions can persist.

In this paper, we examine the adoption of land demarcation systems in the British Empire in the seventeenth through nineteenth centuries, with a particular focus on colonies settled by British emigrants in temperate areas of North America, Australia, and New Zealand.[2] In the British Isles, the traditional land demarcation practice is that of metes and bounds (MB), a decentralized process in which individuals define property boundaries with respect to natural features and adjacent parcels without restriction. There is no centralized demarcation arrangement to align borders, provide usable plot shapes, avoid boundary conflicts from overlapping claims, and facilitate infrastructure along borders. Individuals can bargain locally to make such adjustments through parcel trades, but the demarcation system itself does not do this.

Although MB was firmly entrenched in Britain and throughout the world, the acquisition of vast new territories prompted debate on how to best design and manage land distribution and demarcation in the colonies so as to promote orderly settlement, encourage economic growth to accommodate immigration, and generate higher land values and sales revenues. These issues were debated by leading political economists of the time, including Adam Smith, Jeremy Bentham, John Stuart Mill, Thomas Malthus, David Ricardo, Edward Wakefield, and Robert Torrens (Winch 1965). As an indication of this discussion, the British Colonial Office (Labaree 1967) and, especially, Wakefield (1834) called for synchronized, planned settlement and land demarcation in the British colonies.

As we show, in parts of the British Empire, centralized demarcation—especially the highly organized and uniform rectangular system (RS)—was adopted. A key advantage of the RS was that parcel information was standardized and simplified in a way that promoted land markets and provided other advantages that we describe in this paper. Despite these advantages, some regions in the empire chose to implement mixed systems (MXs) that were centrally controlled but

[1] History is replete with such conquests and expansions: from ancient Rome 2 millennia ago, to the British Empire between the seventeenth and twentieth centuries, to the Soviet regime of the twentieth century.

[2] In this regard, we follow Acemoglu, Johnson, and Robinson (2001) and Crosby (1986), who also focus on the neo-Europes, where settlers tried to replicate European institutions. Primary examples include Australia, New Zealand, Canada, and the United States.

allowed flexibility and variety in demarcation arrangements, and other regions followed traditional decentralized MB.

In this paper, we examine the determinants of these institutions. We develop predictions from an economic model that compares net revenues from the three demarcation systems for a given region and then detail how these values change with exogenous land characteristics. We provide empirical support for our predictions through both historical and quantitative analysis. We find that centralized demarcation systems provide clear benefits from coordinating demarcation, but their adoption is less likely when implementation is slow and controlling settlement is costly. In centralized demarcation, we find that adoption of uniform RS is more likely adopted in large regions with potentially active land markets, where network gains are magnified, but is less likely in rugged terrain, where its rigid uniform structure limits adaptation and increases setup costs.

Our analysis of demarcation institutions is guided by the fundamental insights of Ronald Coase. In his pioneering work, Coase (1937, 1960, 1988) was first to develop (or imply) a theory of institutional choice when he stated that judges choose the most efficient legal regimes. This work led to discussions of the evolution of legal rules and, indeed, to the law and economics movement and, later, to studies of institutions by North (1990), North, Wallis, and Weingast (2009), Acemoglu, Simon, and Robinson (2001, 2002, 2005), and others. Moreover, as the remark quoted above indicates, Coase (1988) clearly understood that markets themselves are institutions that facilitate trade and indeed "require the establishment of legal rules" for them to function.[3]

Ironically, many of Coase's most famous examples have to do with land. In "The Problem of Social Cost," Coase used the example of land use conflicts between wheat farmers and cattle ranchers, and his examination of English law focused on nuisance (that is, land use) disputes. In his theory, he discussed the importance of the "delimitation of rights" to land (Coase 1960, p. 8). However, Coase did not examine in detail how rights to land are actually demarcated, nor did he acknowledge that the demarcation of land in his native England is so different from that in his adopted home of Chicago. However, as Coase would certainly acknowledge, the practicalities of land demarcation are fundamental because they mold land markets and shape land use. Coase, of course, was not alone in overlooking land demarcation. There is little legal or economic scholarship on the factors influencing demarcation, and even major property law treatises (for example, those by Dukeminier and Krier [2002] and Merrill and Smith [2007]) merely describe the dominant American system.[4]

[3] See Coase (1988, pp. 10–14) and Scott (1998, pp. 256, 351) for information on the role of underlying institutions in markets.

[4] Neither of the comprehensive treatises on law and economics by Posner (2002) or Shavell (2004) mention land demarcation. Demarcation, on the other hand, is examined by economic geographers in describing the use of mapping and cadaster systems. For examples, see Scott (1998) and Kain and Baigent (1992). Libecap and Lueck (2011b) and Libecap, Lueck, and Lopes (2012) find that

In Section 2, we briefly summarize land demarcation in the British Empire. In Section 3, we develop a model for assessing the decision to adopt particular demarcation systems. In Section 4, we examine the implications of our model by investigating the detailed history of land demarcation in the British colonies and by econometrically assessing the determinants of those institutional choices. We summarize our study in Section 5.

2. Land Demarcation in the British Empire

The British Isles comprise 121,673 square miles. At its peak, the British Empire covered 14.2 million square miles, nearly 25 percent of the world's land area, and the colonial area that we examine involved 10.7 million square miles (Figure 1).[5] The accumulation of these vast expanses of land beyond the home islands generated the practical problems of how this land should be allocated and how it should be demarcated. These decisions were influenced both by the institutions that were developing in Britain at the time of expansion and by the political economy debates that emerged around colonial policies.

2.1. The British Isles

By the mid-seventeenth century, land in Britain was becoming more valuable, and this led to shifts away from traditional practices and toward implementation of changes in land institutions that subsequently influenced British colonial policy. For example, the enclosure of scattered and common lands helped to restructure, reshape, and consolidate plots of land into more useful forms for sheep raising and larger scale food production. Land that previously had been held and worked either in common or in strips was reorganized into plots owned in severalty and, in some cases, merged into rectangular forms that were recognized as beneficial for production and trading (Turner 1980; Young 1808).[6] Land markets, which historically generally had been local and limited, became more active and broadly based (Darby 1973, pp. 302–53). To promote trades, Parliament intervened between 1660 and 1830 with approximately 3,500 estate acts to free property rights from traditional constraints of inheritance and other

there are economically and statistically significant gains in land values resulting from enactment of a systematic rectangular system (RS) in the United States.

[5] By comparison, Africa comprises just 20 percent of the earth, and Russia, the largest country, comprises approximately 11 percent of the earth. The total land area of the earth is 57,308,738 square miles (see EnchantedLearning.com, The Continents: Land Area [http://www.enchantedlearning.com/geography/continents/Land.shtml]). See also Ferguson (2004, p. 15).

[6] The emergence of rectangular fields as a result of some enclosures is noted by Yelling (1977, pp. 120, 123, 131, 138). The literature on enclosures is very large, and we only point to parts of it. For additional discussion of the geography of enclosure, see Kain, Chapman, and Oliver (2004). Scott (1998, pp. 24–49) discusses the expansion of survey and drafting of cadastral maps in the seventeenth through nineteenth centuries. Allen (1982) finds that there were important effects of the redistribution of enclosures from farmers to land owners, open and enclosed fields often were equally efficient, and efficiency gains were regionally specific.

Figure 1. The British Empire and temperate colonies

communal requirements (Bogart and Richardson 2009, p. 3; Richardson and Bogart 2008, pp. 7–18).

These changes in land institutions required more accurate measurement and boundary definition and standardization of processes. More precise survey was made possible with new procedures and equipment—in particular, the introduction of Gunter's chain in 1620—that spread throughout England and subsequently to the English colonies. Gunter's chain helped to generalize the use of a standard statute rod of 16.5 feet for land measurement by surveyors. Other new equipment and practices, including telescopes, the solar compass, the triangulation survey, and the theodolite survey, emerged over time and influenced the costs and benefits of demarcation.[7]

2.2. The Temperate British Colonies

Figure 1 shows the colonies in North America, Australia, and New Zealand within the larger British Empire.[8] The addition of these colonies opened vast amounts of new temperate land for British colonists. Abundant land in these regions offered the possibility of transplanting British farms, agricultural practices, crops, and land institutions. The question of how to design and manage colonization became part of debates on British political economy in the seventeenth through nineteenth centuries, and demarcation of land was a central issue.

A key question was whether land should be allocated in a decentralized, unsystematic manner, with individual land claims and demarcation done through traditional English MB. "Metes" refers to property boundaries defined by the measurement of distances between terminal points, and "bounds" refers to boundary descriptions based on topography. Under MB demarcation in the colonies, occupied parcels were to be surveyed independently after settlement, generally leading to nonuniform, uncoordinated shapes, sizes, and alignment.[9]

An alternative was to allocate and demarcate land in a more organized, systematic manner, with survey of land parcels occurring before distribution and occupation. New territories in the empire provided the opportunity to implement a centralized system. Coordinated demarcation could be in a local area, organized by a particular colonial group or large land owner, or it might be broader, covering a larger jurisdiction, organized by a government. Two centralized arrangements, RS and MX, were considered and implemented in the colonies; both

[7] Gunter's chain ingeniously linked the measurement of area and perimeter into square parcels using the English system of measurement (that is, inches, feet, yards, and miles). Richeson (1996, pp. 140–75) discusses the introduction and spread of Gunter's chain as well as other survey innovations. Linklater (2002, pp. 13–20) describes the impact of Gunter's chain on measurement and the opportunity to firm private property rights to land.

[8] Figure 1 is modified from a figure found in Wikimedia (http://meta.wikimedia.org/wiki/File:The_British_Empire.png).

[9] See Libecap and Lueck (2011a, 2011b) for a discussion; also see Wikipedia, Metes and Bounds (http://en.wikipedia.org/wiki/Metes_and_bounds).

required initial survey before occupancy, but MX did not define uniform square parcels.

The use of square grids in smaller areas had a long history in England.[10] Colonial towns often were laid out in square blocks (Thrower 1966, p. 9), and Robert Torrens and Edward Gibbon Wakefield, two important nineteenth-century political economists and politicians, called for the strictly planned distribution of all colonial agricultural land and controlled settlement to create productive colonies (Winch 1965, pp. 56–93).[11] One element of Wakefield's colonial reform movement was the survey of land into squares before sale and occupation (Winch 1965, pp. 113–45; Oldham 1917, pp. 4, 16, 74; Burroughs 1967, pp. 12–13). Squares offered potential productivity gains as well as clear boundaries and uniform parcels for exchange in land markets.[12] Wakefield argued that allowing individualized claiming and demarcation with uncoordinated MB would lead to title confusion, a lack of market organization, and economic failure. Accordingly, the interests of individuals to independently claim land could diverge from the broader interests of colonial society, which would be molded by the way in which land was demarcated (Winch 1965, p. 137).

The potential benefits of more centrally controlled, planned demarcation were incorporated in circulars issued by the British Colonial Office in the late seventeenth and eighteenth centuries: "First, that you, our said governor . . . of our lands for the [northern, southern] district of North America . . . taking care that such districts so to be surveyed and laid out as aforesaid be divided into such a number of lots (each lot to contain not less than one hundred nor more than one thousand acres) as our survey general shall judge best adapted to the nature and situation of the districts so to be surveyed. . . . That so soon as the said survey shall have been made and returned as aforesaid, you, our said governor or commander in chief of our said province . . . appoint such time and place for the sale and disposal of the lands contained within the said survey to the best bidder."[13]

3. A Model for Examining Institutional Choice

In this section, we examine the decision to adopt a particular land demarcation system from the point of view of a colonial authority interested in maximizing

[10] Rectangular systems had also been used extensively by the Romans and had been used across Europe in selected areas, so the idea had been tested to a degree (Libecap and Lueck 2011a).

[11] Torrens, originally from Ireland, became premier of South Australia and, later, a member of the British Parliament. He is widely known for creating the system of land registration that goes by his name. Wakefield was a leading colonial policy theorist who was especially interested in the centralized demarcation of lands in South Australia, New Zealand, and, later, Canada. He was a director of the New Zealand Company, a cofounder of the colonial reform movement, and a member of the New Zealand Parliament. See Torrens (1821).

[12] Other aspects of the colonial reform movement included constraints on the supply of new lands made available at any point in time and high fixed prices to control internal migration.

[13] For similar instructions for various other colonies see Labaree (1967, pp. 537, 540–41, 586–87).

Table 1
Three Land Demarcation Regimes

Characteristic	Rectangular Survey System	Mixed System	Metes and Bounds
Controlled entry	Yes	Yes	No
Prior survey	Yes	Yes	No
Plot shape	Rectilinear	Varies	Idiosyncratic
Plot alignment	Yes (often north-south)	Varies	No
Fully contiguous	Yes (in region)	Varies	No

revenue from land sales (Labaree 1967, p. 536).[14] Although not all colonial officials had this explicit objective, some clearly did, such as the Virginia Company and its shareholders. In all cases, however, colonizing authorities were anxious to promote the economic well-being of their dominions, which is consistent with land revenue maximization, when land was the key asset.

Our analysis is centered on the choice between three types of demarcation found in the British Empire: decentralized MB, a centralized RS, and a centralized MX. Table 1 summarizes the key features of these three land demarcation regimes. We denote the expected net revenue for each system as V^{MB}, V^{RS}, and V^{MX}. To arrive at testable implications, we analyze authority's decision to adopt a particular system in two steps, as illustrated in Figure 2. First, we analyze the choice between centralized and decentralized demarcation with respect to exogenous conditions of the region. Second, we focus in centralized demarcation regimes and analyze the choice between a standardized RS and a more flexible MX.

3.1. Decentralized Metes and Bounds

We begin with the analysis of the MB demarcation system. Consider a region of size A with n identical claimants indexed as $i = 1, \ldots, n$. Under MB, a claimant is free to choose the spatial dimensions of his property, including its perimeter (p_i), area (a_i), and location (l_i). For our purposes, the location variable captures the position and alignment of a parcel with respect to other parcels in the system. We denote the location structure of the entire region as $L = \{l_l, \ldots, l_n\}$.

We assume that claimants choose parcel dimensions in a noncooperative way to maximize the value of their claim less the costs of demarcation. We denote the instantaneous value function for parcel i at time τ as $v_{i\tau}(p_i, a_i, L; q)$, where q is an index of land quality such that $\partial v_{i\tau} / \partial q > 0$. This function represents the value generated from a parcel, net any enforcement and transaction costs in a given period. We also define a one-time demarcation cost function that occurs

[14] In using revenue maximization, we ignore redistributive political economy and the details of selling land, such as price setting and parcel size.

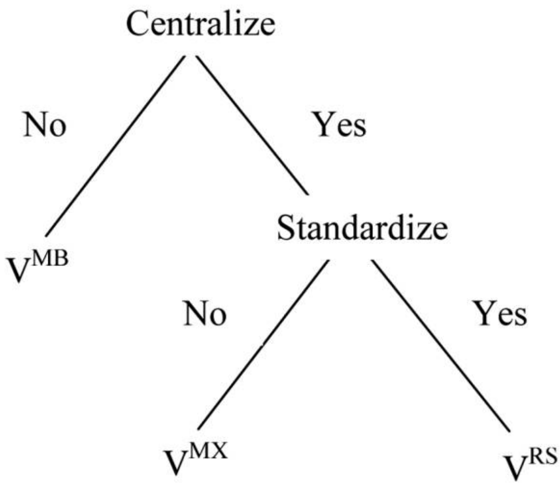

Figure 2. Decision tree for colonial demarcation choices

at time 0 as $c_{i0}(p_i, a_i, L; t)$, where t is a parameter measuring the ruggedness of topography.[15]

Notice that the functions depend on the perimeter, area, and location of parcel i as well as on the location of other parcels in the system. The interpretation is that the uncoordinated location choice of a claimant can lead to misalignment in parcels, unproductive parcel shapes, gaps in the land, and boundary disputes that generate costs across multiple parties. We will refer to these as location effects that can be internalized in a coordinated, centralized system. Accordingly, we expect individual enforcement costs to fall and the total productive value of the land to rise as parcel locations are better synchronized and coordinated with those of the group. Similarly, we expect average demarcation costs to fall as more boundaries are shared. As we note below, these are not guaranteed in a noncooperative MB setting.

The claimant's demarcation problem then is to maximize the net value of his claim, taking topography, land quality, and the location choices of others as given. Formally, claimant i solves

$$\max_{p_i, a_i, l_i} \int_0^T v_{i\tau}(p_i, a_i, L; q)e^{-r\tau}d\tau - c_{i0}(p_i, a_i, L; t), \tag{1}$$

where T is the time horizon and r is a discount rate. We denote the Nash

[15] We do not include t in the parcel value function to simplify the analytical model. This simplification does not change the predictions derived from the model, however. We elaborate on the potential implications of the interaction between terrain and productivity at the end of this section.

equilibrium solution to this problem as the set ($p^\star$, $a^\star$, $L^\star$) and the equilibrium behavior of person i as ($p_i^\star$, $a_i^\star$, $l_i^\star$).

This solution is defined by two important characteristics: shape and alignment/location. First, the optimal shape for individual parcels is expected to be square in the case where there are no location conflicts or topographical impediments to demarcation (flat land).[16] Rugged topography, however, can significantly influence the costs of demarcation, and thus we expect rational agents to deviate from squares in these cases, so that with increases in ruggedness, parcel shapes and sizes will be more irregular and varied, mimicking topography (Libecap and Lueck 2011a, 2011b). Second, the demarcation solution implies uncoordinated location choice. In the absence of coordination, individuals will not account for the effects that their choices have on the rest of the group, and there exist other location arrangements that achieve a higher total value for the region than the equilibrium. Accordingly, decentralized demarcation will tend to lead to more haphazard alignment, less contiguity, and more boundary conflicts than a centrally planned arrangement or one in which all claimants contract with each other to join a system.

The solution to equation (1) implies the value of land sales under MB. Under the assumption that the colonial authority sells land at its net present value, the total revenue received from land sales at time 0 is

$$V^{\mathrm{MB}} = \int_0^T V_\tau^\star e^{-r\tau} d\tau - c_0, \tag{2}$$

where $V_\tau^\star = \Sigma_i^n v_{i\tau}(p_i^\star, a_i^\star, L; q)$ and $c_0 = \Sigma_i^n c_{i0}(p_i^\star, a_i^\star, L^\star; t)$.

3.2. Centralized Demarcation: Rectangular System and Mixed System

Under a centralized demarcation system, a colonial authority (land company, colonial charter holder, or government) sets the initial demarcation rules for parcels in the system and retains control over the land until demarcation is complete.[17] Before sale, the colonial authority incurs the up-front administrative costs of planning, surveying, and controlling settlement over the duration of the setup period. Our centralized MB system cost distinction is similar to Dixit's (2003) difference between local (informal) and large (formal-legal) trading systems, where the latter have large setup costs. We denote this setup time as $\tau' > 0$ and the setup cost in each time period as $C_\tau'(A; t)$. We assume that setup

[16] Evidence from the agricultural engineering literature suggests that rectilinear farm shapes have considerable production advantages over alternative shapes (Barnes 1935; Lee and Sallee 1974; Amiama, Bueno, and Alvarez 2008). Barnes (1935) and Lee and Sallee (1974) show production advantages in rectangular fields where the farmer works parallel to the longest sides of the field. Squares have the lowest perimeter-to-area ratio among rectilinear shapes and therefore minimize survey, fencing, and enforcement costs for a given area of land (Johnson 1957; Libecap and Lueck 2011a). Libecap and Lueck (2011b) provide empirical evidence of a preference for square parcels in flat terrain under decentralized metes and bounds (MB).

[17] Controlling for different ownership regimes in British colonies is difficult because some shifted from one type to another. We examine these issues given the information that we have in Section 4.

costs are increasing in the ruggedness of topography so that $\partial C'\tau/\partial t > 0$. The objective of the authority is to choose the system parameters that solve

$$\max_{p,a,L} \int_{\tau'}^{T} \sum_{i}^{n} v_{i\tau}(p,\ a,\ L;\ q)e^{-r\tau}d\tau - \int_{0}^{\tau'} C'_{\tau}(A;\ t)e^{-r\tau}, \tag{3}$$

where the first integral represents the present value of revenue generated from the sum of all land sales at τ' and the second integral represents the system setup costs that occur from time 0 to τ'. By maximizing over the sum of all parcel values, centralized demarcation allows for a more complete consideration of location externalities, a coordinated alignment, and contiguous land use, compared to the decentralized MB outcome. In addition, centralized planning provides consistency in property descriptions that reduces boundary uncertainty and conflict.

The net gains of centralization can be viewed by comparing the relative value of the centralized solution (denoted V') and the MB solution. A colonial authority will centralize demarcation when the present value of revenue, less system costs, exceeds the revenue generated under MB—that is, when $V' - V^{\mathrm{MB}} > 0$. This becomes

$$V' - V^{\mathrm{MB}} = \int_{\tau'}^{T} (V'_{\tau} - V^{\star}_{\tau})\, e^{-r\tau}d\tau - \int_{0}^{\tau'} (V^{\star}_{\tau} + C'_{\tau})e^{-r\tau}d\tau + c_0 > 0. \tag{4}$$

Equation (4) has three terms that illustrate the trade-offs of centralization. The first integral represents the increased value of coordinated alignment, the savings on boundary disputes, and other avoided MB costs that accumulate after τ'. The second integral can be thought of as the total cost of setup, which includes the forgone MB output that would have occurred during the period of delayed settlement in addition to the centralized system administrative setup. The third term is the individual MB demarcation costs avoided. From equation (4), comparative statics emerge. The net value of centralized demarcation will increase with the benefits to coordination and decrease with implementation time τ' and the costs of survey and controlling settlement, increase in the expected time horizon T, and decrease with the discount rate r.

Considering forces likely to change model parameters can illuminate these predictions and tie them to the empirical analysis. The colonial authority is more likely to choose centralized demarcation in regions with (1) larger areas, because the gains from coordination accrue over a larger number of parcels, (2) later settlement, because improvements in survey technology lower implementation time, and (3) less rugged topography t, because ruggedness increases the costs of both coordinated survey and control and also decreases the speed of implementation. We also expect costs of controlling settlement to become high when there is an incumbent demarcation system in place or when squatting is prevalent. Expected time horizons may decrease with external challenges to the governing land authority; however, as we explain in the empirical analysis in Section 4, these threats were not significant, and time horizons are effectively constant across our sample.

It is also clear from the model that land quality q is relevant to centralization decisions, but the direction of the impact is contingent on several interacting factors. On one hand, higher values for q increases the first term of equation (4) by magnifying the value lost from awkward parcel shapes and land gaps that arise under MB. Higher quality land also gives added incentive for individuals to dispute uncertain MB boundaries, which will tend to increase the first term. On the other hand, the second term of equation (4) shows that higher values for q will increase the opportunity cost of delaying settlement, thereby decreasing the net value of centralization.[18] Without knowing the relative size of these competing pressures for each region, we cannot make clear predictions about the land quality effect. We still control for q in the quantitative analysis using a soil quality proxy, as it is relevant to the model.

3.2.1. Demarcation under a Rectangular System

As we have noted, centralized demarcation often takes on a very specific form in the RS. Under the RS, all parcels are demarcated as identically sized squares and are located in a perfectly aligned grid. We denote these spatial dimensions as $(\bar{p}_i, \bar{a}_i, \bar{l}_i)$ for all i where $\bar{p}_i/\sqrt{\bar{a}_i} = 4$ and where $\bar{L}$ represents a uniform and contiguous lattice of square parcels. A clear benefit of the $\bar{L}$ structure is that it maximizes the shared benefits that come with alignment and contiguity among the group. Clearly aligned boundaries reduce overlapping claims and the potential for boundary conflicts. In addition, the positioning of identical square parcels on a contiguous grid provides long stretches of straight lines along parcel boundaries where road and related infrastructure investment can occur.

Perhaps most important, the RS structure provides network benefits by creating a universal standard for parcel dimensions and addressing throughout the system in a way that is easily communicated.[19] This standardization process is particularly important for facilitating transactions in land markets. Much in the way businesses standardize processes to limit new information acquisition, the standardization of demarcation rules can significantly reduce informational costs involved in land transactions.[20] Spatial dimensions, which are tied to the pro-

[18] Clearly the time horizon plays a critical role in determining which effect dominates. Under sufficiently short time horizons, the second effect will dominate and the likelihood of centralization will decrease with q. Under longer time horizons, the first effect increases in relative importance.

[19] 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).

[20] In general, exchange in land markets requires potential buyers to expend resources to acquire information about various parcels. These informational transaction costs were often exacerbated in frontier land markets. First, colonists and other potential buyers could be great distances from the site in question, and it was not uncommon for purchases to be made sight unseen. Second, a large share of the land supply in early markets came from absentee owners who also possessed little knowledge of the site. Last, land transactions were risky, and buyers had to be wary of fraudulent claims. As a result of these three reasons, land transfers were often hindered by uncertainty over parcel characteristics (Gates 1968).

ductive value of the parcel, are particularly important to communicate between buyer and seller. By fixing boundary dimensions to a uniform standard and by arranging parcels in a systematic, identifiable way, the RS eliminates the need for buyers to gather idiosyncratic parcel information, and information can be easily communicated over long distances. Large, standardized parcel networks will increase general familiarity with the system and promote greater confidence between buyers and sellers in land markets.

As such, we expect the reduction in transaction costs, conflicts, and related market expansion to increase the price of the land, with all else equal. However, the extensive uniformity required to provide these additional network benefits essentially rules out adjustments to terrain, which can be especially valuable during the survey process. The present value of the RS is

$$V^{\mathrm{RS}} = \int_{\tau^{\mathrm{RS}}}^{T} \overline{V}_{\tau} e^{-r\tau} d\tau - \int_{0}^{\tau^{\mathrm{RS}}} C_{\tau}^{\mathrm{RS}}(A;\ t) e^{-r\tau} d\tau, \tag{5}$$

where the first integral is the revenue generated from land sales, the second integral is the cost of setup, and τ^{RS} is implementation time.

3.2.2. Demarcation under a Mixed System

We refer to a more flexible type of centralized system as an MX, or hybrid system. Unlike the RS, an MX does not impose strict requirements for parcel dimensions and alignment, and therefore the details of each MX can vary. The MX allows for adaptation to terrain to find a balance between the benefits of coordinated demarcation and survey costs. Choosing a more flexible arrangement, however, forgoes the network benefits that accrue from the standardization of RS parcels. In other words, parcels no longer will be uniformly shaped or sized, but borders can be defined centrally for public benefits (reduced conflict or road construction), and plot addressing can occur locally in the system, with parcel addresses with respect to one another as centrally defined or with respect to some synchronized positioning point. We denote the total value of land under the mixed arrangement at time τ as $\tilde{V}_{\tau}$, and we assume $V_{\tau}^{*} < \tilde{V}_{\tau} < \overline{V}_{\tau}$ to indicate the intermediate level of network benefits achieved under MX.

We calculate the net benefit of the MX as

$$V^{\mathrm{MX}} = \int_{\tau^{\mathrm{MX}}}^{T} \tilde{V}_{\tau} e^{-r\tau} d\tau - \int_{0}^{\tau^{\mathrm{MX}}} C_{\tau}^{\mathrm{MX}}(A;\ t) e^{-r\tau} d\tau. \tag{6}$$

Equation (6) is similar to equation (5), albeit with a different implementation time and setup cost function. For simplicity, we assume that $\tau^{\mathrm{RS}} = \tau^{\mathrm{MX}} = \tau'$. We further assume that $(\partial C_{\tau}^{\mathrm{RS}}/\partial t) > (\partial C_{\tau}^{\mathrm{MX}}/\partial t)$, to indicate that MX can lower setup costs by adapting to rugged terrain.[21] Mixed systems are then efficient

[21] Flexibility in the mixed system (MX) may also be expressed through the degree to which demarcation is centralized. In this way, the MX derives its value by economizing on control costs relative to RS. We consider this possibility more explicitly in the empirical analysis.

when there are benefits to providing alignment and coordination relative to MB but when RS uniformity requirements are too costly to impose (for example, in rugged terrain). We thus predict that a colonial authority will choose to adopt a uniform RS over an MX whenever $V^{\mathrm{RS}} - V^{\mathrm{MX}} > 0$:

$$V^{\mathrm{RS}} - V^{\mathrm{MX}} = \int_{\tau'}^{T} (\overline{V}_{\tau} - \tilde{V}_{\tau})\, e^{-r\tau} d\tau - \int_{0}^{\tau'} (C_{\tau}^{\mathrm{RS}} - C_{\tau}^{\mathrm{MX}})\, e^{-r\tau} d\tau > 0. \tag{7}$$

The value comparison between RS and MX is fairly straightforward. The first term reflects the difference in network benefits capitalized into land sale revenues. The second term represents the difference in setup costs. Using equation (7), we can determine that a uniform RS is more likely to be adopted over a flexible MX with (1) larger region size A, because network benefits accrue with the size of the network n and because $A = n\bar{a}_i$, (2) less rugged terrain t, because ruggedness increases RS survey costs relative to those associated with an MX, and (3) later settlement, because implementation times τ' are reduced by improving survey technology, thus making the relative cost advantages under an MX less important. Furthermore, later settlement dates (in our sample) generally correspond to the escalating development of commercial land markets worldwide, which increases the network benefits of RS standardization.[22]

This framework provides the following implications that we can confront using both qualitative and quantitative data on demarcation adoption in the British Empire. First, we predict that a centralized system, instead of individualized MB, will be adopted by colonial authorities when areas are large, when the time horizons are long, when the authority has control over migration and settlement, and when terrain is relatively flat. Second, we predict that when a centralized system is chosen, RS will be selected in less rugged terrain and later in colonial settlement.

4. Empirical Analysis

To test predictions about the choice in land demarcation institutions in the British Empire, we employ two methods. First, we examine the history of colonial land demarcation by examining the literature and the contemporary political debates. Second, we assemble at the colonial level a database that includes information on demarcation institutions and exogenous land characteristics.

4.1. Demarcation across the Temperate Colonies

Our analysis has identified a group of factors that we expect to influence the choice of demarcation regime. Of these forces, two important ones—the lack of

[22] Although MB and MX differ in important ways, they both can be considered flexible demarcation systems. Because equation (7) predominantly reflects trade-offs between uniformity and flexibility, we briefly explore whether these predicted relationships hold more generally when MB is included as a flexible demarcation system in the empirical sample.

an incumbent demarcation system and strong British control over the colonial region—did not appreciably vary across the temperate colonies.

By the time Britain was establishing its North American, Australian, and New Zealand colonies in the seventeenth through the nineteenth centuries, it was the premier world power, and this did not change significantly until World War I. Britain was the home of the industrial revolution beginning in the eighteenth century. It defeated the Dutch and French in North America between 1664 and 1763, and it faced no serious competition in Australia or New Zealand. Spain, another potential competitor, was driven from most of its colonies in the Western Hemisphere between 1810 and 1825. Accordingly, Britain had secure control over its colonial territories, increasing the expected time path of returns of implementing new institutional forms. In terms of local demarcation practices, populations of indigenous peoples tended to be sparse without formal demarcation of the land, or at least by any formal demarcation that was generally adhered to by Britain. The groups were militarily defeated, allowing Britain to implement British land demarcation institutions across its temperate colonies (Linklater 2002, pp. 24–40).[23]

There were, however, other important colonial characteristics that varied, and we use this information to explain differences in observed land institutions. Table 2 describes the different institutions found in the temperate colonies, following the classifications described above and organized by system.

Figures 3,[24] 4, and 5[25] show examples of varying demarcation practices across the empire. The discussion of practices across the colonies is ordered according to the type of regime that prevailed in each. Among the variables identified in the framework developed above, historical narratives provide information on the roles of (1) control over land and the population so that survey could precede settlement, (2) time of settlement that indicates access to newer, more accurate survey techniques and equipment that lower the costs of centralized demarcation, (3) terrain that influences the costs of survey, setup, and monitoring control

[23] In the colonial period, only in New Zealand in the North Island were population numbers sufficiently large that natives had more political and military power requiring accommodation. For discussion, see Hailey (1938, p. 713). Population estimates for the temperate colonies at the time of settlement are limited. Some sources are Borah (1976, pp. 13–34), Pool (1977), and Vamplew (1987).

[24] Figure 3 is adapted from Price (1995, p. 8). Price's federal rectangular grid corresponds to our rectangular system; division into townships, to our mixed system; and irregular land division, to our metes and bounds classification.

[25] The sources for the information found in Figures 4 and 5 are as follows: for New England, McManis (1975, p. 56); for Ontario, Schott ([1936] 1981, p. 84); for South Australia, Kain and Baigent (1992, p. 315); for New South Wales, Department of Lands (Parish Map Preservation Project, pastoral map of Cardington, image 10075001 (http://parishmaps.lands.nsw.gov.au/mrsid/show_map.pl?client=pmap&image=PMapEast02/10075001.sid&mapval1=CARDINGTON&mapval2=560&maptype=PL); for Victoria, Honeycombe Archive, Maps, Ordnance Survey map of West Cornwall, 1853–93 (http://www.honeycombe-archive.com/thegreatwork/10maps/html/map04.html); and for New Zealand, Don Armitage Web site, Great Barrier Island History, Maps and Charts of Great Barrier Island, 1880 map (http://sites.google.com/a/aotea.org/don-armitage/_/rsrc/1233729039315/Home/great-barrier-island-history/maps---charts-of-great-barrier-island/1880%20map%20gbi2.jpg).

Table 2
Land Demarcation Systems in the British Empire

Jurisdiction	Demarcation System
U.S. federal lands	RS
Canadian Dominion lands	RS
South Australia	RS
Ontario, Canada	RS
Victoria, Australia	RS
New Zealand:	
Otago	MX
Nelson	MX
Wellington	MX
Canterbury	MX
Hawkes Bay	MX
Taranaki	MX
Connecticut	MX
Rhode Island	MX
Massachusetts	MX
Maine	MX
New Hampshire	MX
Nova Scotia	MX
New Brunswick	MX
Quebec	MX
Georgia	MB
South Carolina	MB
North Carolina	MB
Virginia[a]	MB
Maryland	MB
Delaware	MB
Pennsylvania	MB
New Jersey	MB
New York	MB
New South Wales	MB
Tasmania	MB
Queensland	MB
West Australia	MB

[a] Includes what is now Kentucky and West Virginia.

over settlement, and (4) land quality that influences agricultural land values, farm size, and population densities, as well as the opportunity cost of delayed settlement under centralized demarcation.

4.1.1. Metes and Bounds Demarcation

Metes and bounds demarcation was used in the southern American colonies, the middle Atlantic colonies, New South Wales, Tasmania, Queensland, and Western Australia. These were all relatively early colonies, with most of them established in the seventeenth and early eighteenth centuries, so settlement and demarcation took place with more primitive, costly survey instruments, making centralized demarcation setup more difficult and protracted. Although there were early plans for more centralized demarcation in Georgia and South Carolina,

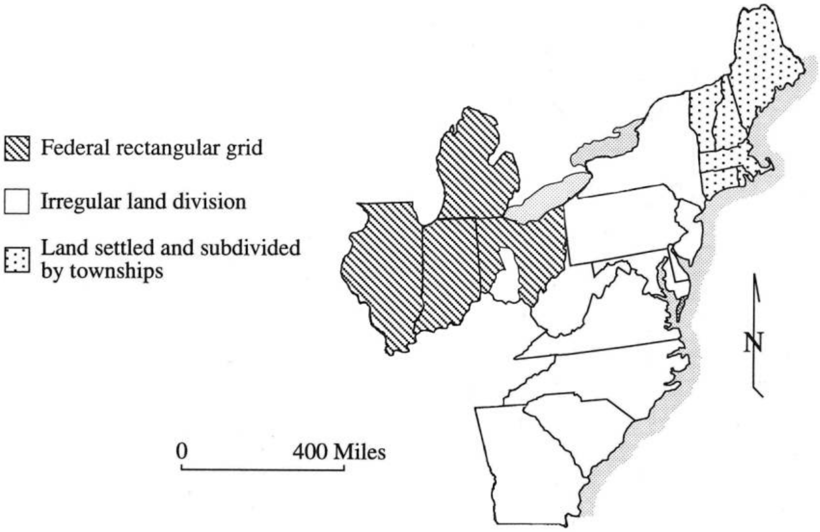

Figure 3. Early U.S. demarcation systems

these failed.[26] There was little control over the internal migration of land claimants in the southern American colonies, and rugged terrain reduced the attractiveness of the area for agriculture. As colonial immigrants moved into the interior, land areas were indiscriminately selected, settled, and then surveyed in a haphazard manner using MB. As a result, there was little consistency in parcel shapes, sizes, or alignment, and boundaries were vague and often disputed. Swamps and irregular terrain also made more systematic survey costly (Linklater 2002, pp. 32–40).

In the middle Atlantic colonies, William Penn, who was granted the territory of Pennsylvania in 1681, also had envisioned centralized land distribution with contiguous tiers of townships of 5,000 acres square with rectangular plots, surveyed prior to settlement, moving west from the Delaware River. However, this also generally did not occur in Pennsylvania or elsewhere in New Jersey, New York, or Delaware, where there was only loose colonial control over the occupation of land in rugged terrain, and parcels were haphazardly defined before survey (Marschner 1960, pp. 27–34, 35; Price 1995, p. 212).

Limited control, rough terrain, and variable soil quality also led to MB demarcation in the early Australia colonies of New South Wales (established in 1778), Tasmania (1803), Queensland (a part of New South Wales until 1859),

[26] See Marschner (1960, pp. 22–24, 33–36), Kain and Baigent (1992, pp. 269–76), Price (1995, p. 97) on free land choice, Price (1995, p. 7, 15–18, 87–205) for discussion of the southern colonies, Thrower (1966, p. 10), Johnson (1957, p. 22), Kinda (2001, p. 143), and Mitchell (1983).

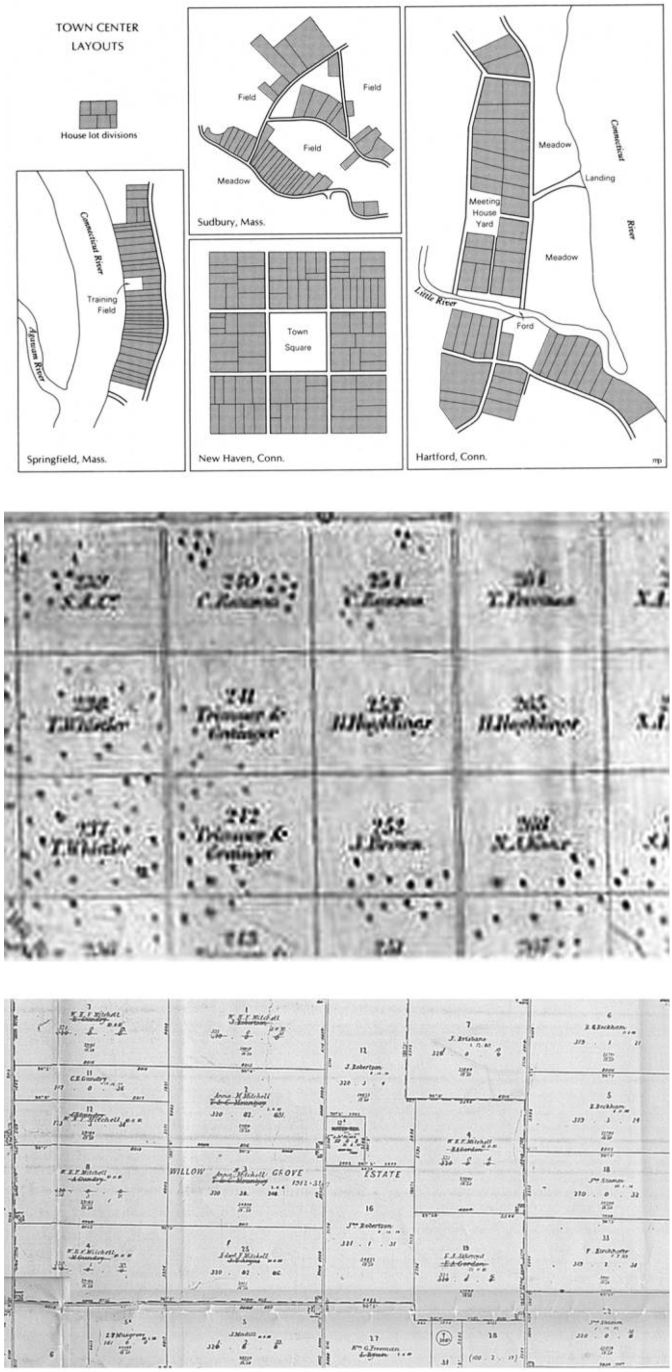

Figure 4. Land demarcation practices in the British colonies. Top, mixed demarcation, New England townships; middle, RS demarcation, South Australia; bottom, RS demarcation, Victoria, Australia.

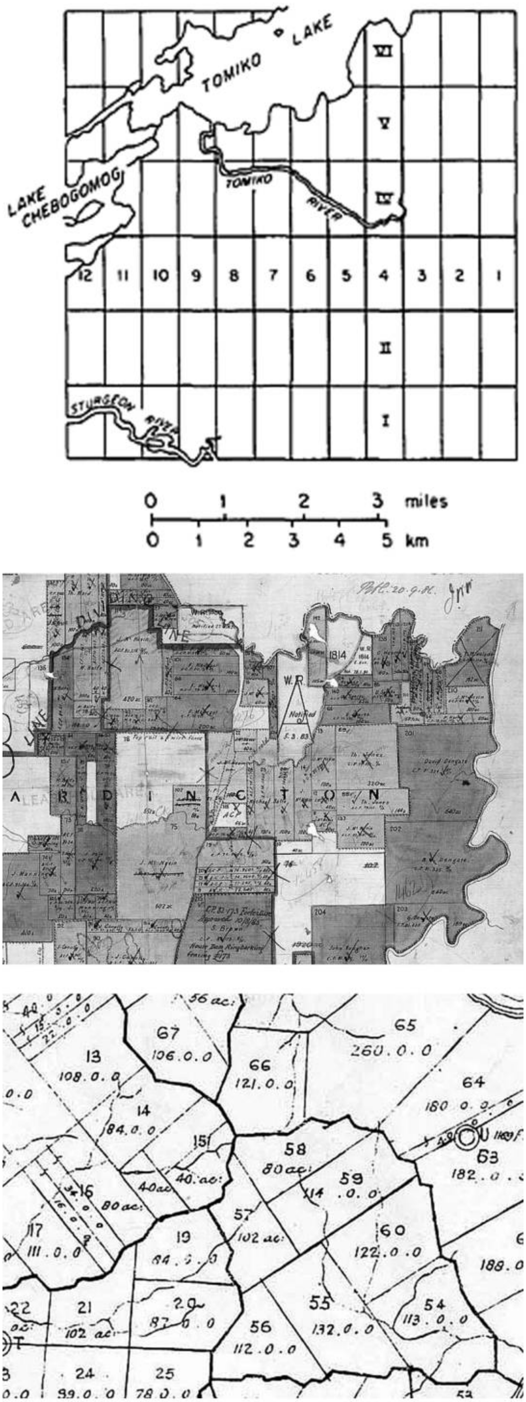

Figure 5. Land demarcation practices in the British colonies. Top, RS demarcation, Ontario, Canada; middle, MB demarcation, New South Wales, Australia (© Land and Property Management Authority, Panorama Avenue, Bathurst NSW 2795 [http://www.lpma.nsw.gov.au]); bottom, mixed demarcation, New Zealand.

and Western Australia (1826). New South Wales and Tasmania began as penal colonies for Britain and not initially as locations for emigration to new land. As a result, there was little constraint on internal migration and land claims. Although instructions to colonial governors called for British institutions to be implemented for planned, centralized allocation and survey of land into small farms under RS, these instructions could not be enforced. As a result, claiming and demarcation was much more ad hoc under individualized MB.

In the interior of New South Wales, rough terrain increased the costs of systematic demarcation strategies, and semiaridity increased the need for claimants to disperse, reducing potential network gains for centralizing demarcation in a given region (Jeans 1966, pp. 125–27; 1967, pp. 243–54; Kain and Baigent 1992, pp. 307–10). Efforts to implement plans for centralized survey and distribution via an RS in 1821 failed (Winch 1965, pp. 94–108; Jeans 1966, pp. 119–23).[27] Queensland and Tasmania (or Van Diemen's Land) were initially administered as part of New South Wales, but little planning in settlement was done before they became separate territories in the mid-nineteenth century (Kain and Baigent 1992, p. 307; Jones 1989, p. 41). The same terrain problems and lack of control over land claiming led to the dominance of MB in both Queensland (Jeans 1966, pp. 122–23; Kain and Baigent 1992, p. 307) and Tasmania (Jones 1989, p. 75).[28] As in New South Wales, the most arable land was occupied by individuals and then surveyed under decentralized MB. Although not adjacent to New South Wales, Western Australia faced similar problems of controlling settlement prior to survey, coupled with very dry terrain and mixed soil quality that did not blend with a small, systematic land distribution policy.[29]

4.1.2. Demarcation in a Rectangular System

Rectangular systems were used to demarcate land in the (U.S.) federal public lands, the Canadian Dominion lands, Ontario, New Brunswick, South Australia, and Victoria. These regions have characteristics distinct from those in which MB was established. They were settled relatively later, generally in the late eighteenth and early to mid-nineteenth centuries. These regions are characterized by large land areas, flat terrain, and fertile soil; more effective control over internal migration; and improvements in survey technology. Our analysis implies that these factors would facilitate survey prior to settlement into RS.

The advantages of the broad, uniform rectilinear demarcation of land were recognized in the United States at the end of the colonial period, during con-

[27] Similar arguments are found in Jeans (1975).

[28] Information was also obtained from Brownwyn Meikle, University of Tasmania postgraduate student studying early land policies, e-mail to Libecap, January 14, 2010. See also McKay (1962) for discussion of Tasmanian survey and land demarcation.

[29] Jeans (1975, pp. 3–5) discusses the general problem in Australia of limited good farm land and dry conditions that favored pastoral pursuits rather than farming. For problems with squatting and free homesteading in Queensland and Western Australia, see Williams (1975, p. 94). See Kain and Baigent (1992, pp. 307–9) for reference to unregulated distribution of land in huge parcels in West Australia (Swan River colony).

gressional debates over the Land Ordinance of May 20, 1785, which ultimately resulted in the Public Lands Survey System (PLSS) (Ford [1910] 1976, pp. 27, 55; Linklater 2002, pp. 116–17; Pattison 1957, p. 87).[30] The law gave government authority over demarcation and settlement as a condition of granting individual titles. Congress rejected MB and instead called for survey before occupation, with properties to be marked in squares and aligned with each other.[31] The land was surveyed into 6-mile by 6-mile townships (480 chains per side) and subdivided into 36 sections of 1 square mile each before sale and settlement (Linklater 2002, pp. 68–72; White 1983, p. 9).[32]

The PLSS was inaugurated for the comparatively flat and rich soils of the Midwest and was gradually extended across the Great Plains. The RS was adopted because of its ability to promote "an orderly settlement of new lands"; prevent the scattered and uneven claiming of only the best lands, "leaving vacant and uncultivated, in such irregularity, small and incommodious parcells that it is thought scarcely worth any one's While"; reduce land boundary conflicts and "prevent innumerable frauds and enable us to save millions"; and, importantly, raise land values and revenue so "these Lands will provide a considerable resource for sinking the national debt, and, if rightly conducted, liten the burthens of our fellow-citizens on account of Taxes as well as give relief to the creditors of the United States" (Ford [1910] 1976, p. 15).[33]

In Ontario, beginning in 1763, the flat and fertile land along the Great Lakes and Saint Lawrence River also was demarcated in a grid with 6-mile-square townships as a standard, although there was variation in township and subdivision size across the province. Near lakes, narrow, rectangular long lots also were used (Kain and Baigent 1992, pp. 298–303; Taylor 1945, pp. 90–92; Thomson 1966, pp. 237–43). Similar demarcation was practiced to the south and east of the Saint Lawrence River in Quebec, in a region called the Eastern Townships, and in the colony of New Brunswick (established in 1784) (Kain and Baigent 1992, p. 298; Taylor 1945, p. 89; Thomson 1966, pp. 99, 224–25; Schott 1980). The Dominion Land Survey (DLS), which began in 1871, was implemented in the Prairie Provinces of Canada to parallel the PLSS in the United States, with

[30] See also NationalAtlas.gov, The Public Land Survey System (http://www.nationalatlas.gov/articles/boundaries/a_plss.html). A survey technique used in the nineteenth century was triangulation (Wikipedia, Triangulation [http://en.wikipedia.org/wiki/Triangulation]). Triangulation involves measurement of the angles of a series of triangles to fix property location and boundaries. If done in an organized manner, parcels could be demarcated with respect to one another.

[31] It seems likely that American colonial leaders and, later, government leaders were influenced by British intellectual discussions of land demarcation. These individuals traveled to England and elsewhere in Europe and studied conditions there. We, however, have not located direct links between congressional arguments and the statements of British political economists on demarcation.

[32] As described by Pattison (1957, pp. 49–51), the American RS used Gunter's chain with 10 square chains to the acre, a mile divided into 80 chains, and a square mile divided into 640 acres (White 1983).

[33] These observations by Amelia Clewly Ford ([1910] 1976, p. 15) come from her description of a letter written by Governor Sharp of Maryland to Lard Baltimore in 1754. See also Kain and Baigent (1992, pp. 289–92) and Cazier (1976).

land surveyed into 6-mile-square townships that were aligned and addressed along lines of latitude and longitude (Kain and Baigent 1992, p. 303; Taylor 1975, p. 11; MacGregor 1981).

In Victoria, Australia (separated from New South Wales in 1851), RS was used as the agricultural frontier moved northwest beyond Port Philip (Melbourne) in the 1850s. The main cadastral unit for surveying and mapping properties was the parish, which varied in size between 15 and 33 square miles. Some parish borders were aligned rectilinearly toward magnetic north, similar to PLSS in the United States. In the Melbourne-Colac-Geelong triangle to the west of Melbourne, parishes were divided into sections of 640 acres and subdivisions of 80 and 40 acres (Kain and Baigent 1992, pp. 311–13; Powell 1970, pp. 51–68; 1975, p. 35).

South Australia (1834) was the definitive planned colony. Colonization was organized after 1835 by the South Australian Land Company. Land was surveyed into rectangular grids, in accordance with Wakefield's philosophy (Winch 1965, pp. 97–110; Burroughs 1967, p. 179; Oldham 1917, pp. 4, 10, 14; Wakefield 1834, pp. 3–19). Wakefield wanted "to prevent 'a few good judges of their own interests' from buying up all the available profitable, waste lands" and avoid the "injurious" dispersion of settlement where "each settler became the proprietor of a small section of land; under such conditions society was impossible" (Oldham 1917, pp. 14–15; Wakefield 1834, pp. 87–89).[34] A land registry system designed by Torrens to facilitate the clear assignment of land rights and active land markets was adopted and represented a break from use of English common-law deeds of transfer (Kain and Baigent 1992, pp. 313–17; Burroughs 1967, p. 179; South Australia Department of Lands 1986, pp. 8, 38; Powell 1972).

4.1.3. Mixed Demarcation Systems

In New England, Nova Scotia, Quebec, and New Zealand, mixed demarcation systems were established. Mixed systems come in various forms but follow the general rules predicted by the framework. In contrast to MB, the MX exhibited greater control over settlement, and demarcation and survey occurred prior to occupation; however, they also lacked the uniformity of RS. These colonies generally also had rough terrain that raised survey costs of uniform demarcation and limited the use of RS. In terms of timing, all but New Zealand (which was largely settled in the nineteenth century) were early colonies dating from the seventeenth century.[35] Quebec was colonized by France beginning in 1608, and French land demarcation was incorporated by the British. All MXs were flexible in the demarcation patterns that they implemented, but the earlier systems were also flexible in the extent of centralization that they imposed. This

[34] Wakefield (1834, pp. 99–103) admired the U.S. federal lands policy.

[35] New England included Massachusetts (settled in 1620 for Plymouth and 1628 for the Massachusetts Bay Colony), Maine (1622), New Hampshire (1623), Rhode Island (1636), and Connecticut (1633). Settlement of Nova Scotia occurred in 1621, while settlement of New Zealand largely occurred in the nineteenth century after 1838.

timing suggests the use of primitive survey technology in earlier settlements, which, with all things equal, would increase the costs of extensive centralized systems such as the RS. On the other hand, most of these colonies were communal settlements with strong ties to the center of the settlement, which effectively lowered the cost of controlling settlement relative to the MB observations (Price 1995). The result was a mixed demarcation system that varied across the colonies.

In New England, land was demarcated into (generally) square townships of 6–10 miles and internally divided into town lots and agricultural plots, including common fields. Proprietors distributed land to the township inhabitants. In the township, properties were not of equal size or uniform shape but instead were based on social standing, wealth, and family size. Settlement was communal, often organized around religious groups from an existing community in England (Marschner 1960, pp. 24–25; Egleston 1886, pp. 21–22, 41–45; Price 1995, pp. 13–14, 28–29; Kinda 2001, p. 142). As settlers moved into the interior, they petitioned colonial governments for land grants that were distributed as new towns or townships (Kain and Baigent 1992, pp. 285–86; Egleston 1886, p. 15). Lands were to be collectively occupied to build a "compact state of freeholders," and they were to be surveyed and marked within 12 months of the township grant. There was limited independent squatting on land (Egleston 1886, pp. 15–18; Price 1995, pp. 28–35). Township locations were not coordinated and could be scattered. This organized pattern of survey and demarcation tended to weaken as migration moved further into the more rugged New England interior (Price 1995, pp. 34–35).

Nova Scotia (settled in 1621) land demarcation patterns were similar to those in New England with local townships. In some cases, townships were large, with 100,000 acres given to a collective group. Individual shares in the township could be as large as 500 acres. The external township lines were surveyed prior to the grant, and the township community was responsible for subdivision (Kinda 2001, p. 142; Thomson 1966, pp. 118–20).

Quebec was made part of the British Empire in 1763, after the signing of the Treaty of Paris. The French crown granted land to seigneurs, who subdivided their grants into individual plots of 60–100 acres in long narrow lots that fronted the Saint Lawrence River. The seigneurs then recruited colonists to occupy and rent their lands. In this way, the land was surveyed and demarcated before settlement, in a manner similar to townships in New England (Harris and Guelke 1977, pp. 135–53; Kain and Baigent 1992, pp. 276–98, 303; Thomson 1966, pp. 38, 76–77).

Demarcation in New Zealand was affected by the control over settlement provided both by Wakefield's philosophies implemented by the New Zealand Land Company organized in 1838 (Winch 1965, pp. 111–13) and by improvements in surveying with triangulation that appeared by the nineteenth century. Triangulation techniques accelerated the implementation of large-scale surveys and made centralized demarcation more feasible. Indeed, the initial plan was to use an RS. Six provinces (Wellington, Nelson, Taranaki, Otago, Canterbury, and Hawke's Bay)—and, later, 10 provinces—were established in New Zealand, and each adopted a separate but similar land demarcation system (Scott 1998, p. 51; Kain and Baigent 1992, pp. 318–19).[36] The New Zealand Company's initial RS worked to some degree in Canterbury, which was relatively flat, but elsewhere it ran afoul of rough terrain and other natural features that raised the costs of demarcating into square sections. An alternative centralized survey system, such as MX, with variable parcel sizes, shapes, and alignment was adopted. However, as opposed to MB, the centralized system provided systematic location, addresses, and well-defined boundaries. It was first used in Otago, and its use spread throughout all of New Zealand by 1876 (Kain and Baigent 1992, pp. 320–24).

4.2. Econometric Analysis Using Data on Land Characteristics

The historical data are consistent with the predictions in Section 3. To more precisely examine those predictions, we now turn to econometric analysis of the adoption of a particular regime.

4.2.1. Data and Descriptive Statistics

With the use of geographic information system data, we compile a data set of land characteristics at the colonial level for each area listed in Table 2. Observations are centered at the initial point of British settlement in the colony and include all land area in a 50-mile radius. By overlaying publicly available spatial data, we calculate variables for terrain ruggedness, soil quality, area governed, and year of settlement. Terrain ruggedness is a measure of average surface slope in a region and is derived from 90-meter digital elevation models (DEMs) generated by the Shuttle Radar Topography Mission (SRTM). Soil quality represents an average of soil quality scores assigned at a 1-kilometer resolution. The score ranges from 1 to 7, with 1 indicating soil unsuitable for agriculture and 7 indicating unconstrained soil. Soil quality data were taken from the Global Agro-Ecological Zones data set. Area governed represents the land area within the boundaries of the observation measured in units of 1,000 square kilometers. More complete descriptions of how the variables were constructed can be found in the Appendix.

Table 3 provides descriptive statistics for the variables in our analysis by demarcation type. On average, RS is observed over large regions with relatively flat terrain and higher-than-average soil quality, which is consistent with the historical analysis presented above. In addition, the reported means for settlement year suggest an increasing level of order and uniformity in demarcation practices over time.

[36] They were combined into a single colony in 1876. Through 1870, most agricultural settlement took place on the South Island (Greasley and Oxley 2009, p. 326).

Table 3
Summary Statistics by Demarcation Type

System Type	Terrain Ruggedness	Soil Quality	Area Governed (10,000 km^2)	Year of Settlement
MB (N = 13)	1.61	3.01	45.7	1,707
	(1.39)	(.74)	(78.7)	(75)
MX (N = 14)	2.36	3.34	13.7	1,746
	(1.33)	(.97)	(35.4)	(99)
RS (N = 5)	1.09	4.32	283.2	1,827
	(.65)	(1.63)	(373.9)	(37)
All (N = 32)	1.85	3.39	68.8	1,743

Note. Means for each system type are reported, with standard deviations in parentheses. MB = metes and bounds; MX = mixed system; RS = rectangular system.

4.2.2. Determinants of Adoption: Ordinary Least Squares Estimates

To understand the relative importance of the variables in Table 3, we estimate the decision to adopt a centralized demarcation system by ordinary least squares (OLS) regression from the following linear regression model:[37]

$$Y_i = \mu + \alpha T_i + \beta S_i + \delta A_i + \theta D_i + \varepsilon_i, \quad (8)$$

where Y_i is a binary outcome variable in which one indicates a centralized RS or MX system (10 observations) in colony i and in which zero indicates decentralized MB (13 observations).[38] In equation (8), T_i is the terrain ruggedness in colony i, and S_i is soil quality (both are in the 50-mile radius of the initial settlement point); A_i is the area governed (size of colony or region in 10,000 square kilometers); D_i is the date of initial settlement in years; α, β, δ, and θ are regression coefficients; μ is a constant; and ε_i is a random error term. Ordinary least squares estimates are reported in Table 4. Given the linear model, we can loosely interpret the dependent variables as response probabilities and the coefficients as marginal effects.[39]

The most salient result that comes out of Table 4 is the clear shift toward centralized demarcation over time. Our main interpretation of this effect is that the progressive development of survey technology over time lowered the costs and increased the speed of implementing a systematic survey that preceded settlement. To get a general idea of the magnitude of the effect of settlement date, the results imply that adoption of centralized demarcation in a temperate frontier setting is 40 percent more likely over a century in the time-frame of

[37] Ordinary least squares regression is chosen over maximum likelihood because of its preferable small sample properties.

[38] As the model distinguishes between centralized and decentralized systems, we exclude observations for New England and Canadian MXs, in which centralization was only partial.

[39] A probit analysis generates qualitatively similar results. The estimated marginal effects are as follows: for terrain ruggedness, .046; soil quality, .055; area governed, .00017; and year of settlement, .0064 ($p < .05$). Heteroskedasticity-consistent standard errors were used in the significance tests in Table 4.

Table 4
Determinants of the Centralization and Uniformity Decision

	Centralization		Uniformity			
			Full Sample:		Restricted Sample:	
Dependent Variable	MB = 0; RS, MX = 1		MB, MX = 1; RS = 0		MX = 0; RS = 1	
Terrain ruggedness	−.0477	(.0618)	−.117**	(.0417)	−.173*	(.065)
Soil quality	.0816	(.105)				
Area governed	.00007	(.0004)	.00085**	(.00017)	.00089**	(.00017)
Year of settlement	.0041**	(.0011)	.0019*	(.0007)	.0022**	(.0007)
R^2	.50		.46		.57	
F-statistic	18.9		21.3		44.3	

Note. Coefficient estimates are reported for an ordinary least squares regression on a [0, 1] binary outcome variable where a value of one indicates centralized demarcation or a uniform rectangular system (RS) demarcation system. Centralized demarcation (N = 29) includes the rectangular system (RS) and fully centralized mixed system (MX) but excludes MX systems in New England and Canada where centralization was only partial. The full sample (N = 32) utilizes all observations in the data set and compares the flexible systems of metes and bounds (MB) and a mixed system (MX) with the uniform, RS. The restricted sample (N = 19) restricts the analysis to only MX and RS systems where an identifiable level of control has been established. Heteroskedasticity-consistent standard errors are in parentheses. MB = metes and bounds.
* Significant at the 5% level.
** Significant at the 1% level.

our sample. The estimated coefficient on terrain ruggedness is negative, as predicted, but it is not statistically different from zero. As seen in the historical analysis, additional confounding factors, such as accounting for political control, may be affecting setup costs and adding noise to the results. Similarly, the estimated coefficient on area governed is positive, as predicted, but not statistically significant. In addition to issues of confounding control costs, these results may indicate that some public benefits to centralized demarcation, particularly in MX regimes, occur over a relatively small range. Last, the insignificant coefficient on the soil quality variable is not surprising, as the direction of the land quality effect was ambiguous in the theory. We can interpret the positive sign of the coefficient as an indication that, on average, the future potential of more valuable land justified the up-front cost of a centralized system.

We next analyze the decision to adopt a uniform demarcation system over a more flexible one by estimating

$$U_i = \mu + \alpha T_i + \gamma A_i + \theta D_i + \varepsilon_i, \qquad (9)$$

where U_i is a binary outcome variable in which one denotes a uniform RS. All other variables in equation (9) are the same as those used to estimate equation (8), except that soil quality is not included. The first specification uses the entire sample and looks at the general tension between uniformity and flexibility. The second specification restricts the analysis to only RS and MX observations, ones in which an identifiable level of control has been established, to more precisely test the predictions from equation (7). Ordinary least squares estimates of equation (9) are reported in Table 4.

The estimates reported in Table 4 are generally consistent with our predictions and historical analysis. The estimated coefficient on area governed is highly significant and supports the prediction that gains from uniform demarcation increase with the size of the network. Both coefficient estimates suggest that an increase in 2 million square kilometers (approximately 250 million acres), or approximately 1 standard deviation, should increase the likelihood of adopting uniform demarcation by 9 percent. The estimated coefficients on terrain ruggedness are negative and significant in both regressions, also indicating the important impact of topography and the increased survey costs of uniform demarcation in rugged terrain.

We also find a positive and significant effect for the year of initial settlement in both samples. The results suggest an approximately 20 percent increase in the likelihood of RS adoption over 1 century. This is consistent with our predictions for two reasons. First, improvements in survey technology increase the speed of implementation of extensive and uniform demarcation systems and reduce the total cost of setup relative to alternatives. Second, as land markets evolved and expanded over time, there was a greater role for parcel standardization in lowering transaction costs.

5. Conclusion

A half century has passed since Ronald Coase taught economists the importance of the fundamental institutions that underlie markets. He pointed out the link between property rights and transaction costs; how legal and other factors determine them; and how these, in turn, shape economic outcomes. These insights have influenced the subsequent work of economists working on transaction costs, property rights, economic organization, and development.[40] Ironically, the institutions of land—one of Coase's original examples—have been neglected in the expansion of institutional economics.

In this paper, we examined the economic history of land demarcation in the expansive British Empire, using the insights of Coase. We developed an economic framework for examining the decision to adopt a particular system of demarcation of rights to land. Using that framework, we analyzed the variation in institutions across the temperate British Empire, ranging from the systematic RS to an organized hybrid system, to unsystematic MB. This variation occurred despite efforts by leading British political economists and colonial politicians, such as Edward Gibbons Wakefield, as well as the British Colonial Office, to implement a planned and controlled RS for the demarcation of land.

We found that a simple model that outlines the costs and benefits of implementing demarcation systems can explain the different institutions that are observed. Once in place, these institutions persist, indicating a strong institutional path dependence that can influence transaction costs, the extent of land markets, and the nature of resource use. The demarcation regimes that we examined in

[40] The list is far too large to do justice to the literatures. In addition to those noted earlier, one would certainly include the work of Barzel (1982), Demsetz (1988, 1997), Williamson (1975, 1985), and others on the theory of the firm.

the United States, Canada, Australia, and New Zealand and that were put into place between the seventeenth and nineteenth centuries remain in force today. In this regard, institutions of land are durable, much as are other institutions, such as language and law.

This persistence of demarcation regimes indicates the costs of institutional change once land has been allocated and parcels developed. Individuals can consolidate or subdivide their properties as necessary through land markets, but restructuring demarcation requires coordination among adjacent land owners in readjusting boundaries, parcel shapes and sizes, fencing, and past capital investments. The costs of valuing and reallocating existing plots and investments are likely to be significant, and holdup is a possibility. Furthermore, the network benefits of a centralized regime are public goods that are not necessarily captured by individuals unless they are very large land owners. Most of the gains require large areas and a stable sovereign to capture long-term benefits. A centralized regime would not be worth the new setup costs for individual property owners. Finally, as we argue, changes in technology can dramatically alter the cost of implementing demarcation systems. Although technology lowered the costs of centralization between the seventeenth and nineteenth centuries, more recent advances in global positioning systems, geographic information systems, and other geographic technologies may serve to make some MB and MX parcels more comprehensible, thereby lowering the advantages associated with the RS.

Appendix

Variables and Data Sources

Observations

Observations are centered at the initial point of British settlement and include all land area in a 50-mile radius. For the U.S. Public Land Survey, we use the point of beginning located in present-day East Liverpool, Ohio, at the coordinates 40°38′32.61″ N 80°31′9.76″ W. For the DLS of Canada, we use the center of Winnipeg as the initial point. Coordinates for initial settlements were obtained elsewhere.[41]

Terrain Ruggedness

Terrain ruggedness measures the average surface slope for the region (Libecap and Lueck 2011b). The measurement is derived from 90-meter DEMs downloaded from the Consultative Group on International Agricultural Research Consortium for Spatial Information.[42] The DEMs are generated from the Shuttle Radar Topography Mission (SRTM) of the National Aeronautic and Space Ad-

[41] University of North Carolina, Coordinate Systems for Google Maps (http://facstaff.unca.edu/mcmcclur/GoogleMaps/Projections/GoogleCoords.html).

[42] Consultative Group on International Agricultural Research Consortium for Spatial Information, SRTM 90m Digital Elevaltion Data (http://srtm.csi.cgiar.org).

ministration and are further processed by the International Centre for Tropical Agriculture to fill voids in the data set. We exclude water bodies in our measurement of terrain ruggedness by removing areas in the DEM that overlap data from the SRTM Water Body Database (SWBD). The SWBD data were obtained online.[43]

Soil Quality

Soil quality is based on a seven-point score measuring constraints on soil fertility from the Global Agro-Ecological Zones (GAEZ) data set downloaded from the International Institute for Applied Systems Analysis at 30-arc-second resolution.[44] We reverse the order of the GAEZ ranking to reflect quality of the soil rather than constraints. A score of 1 indicates that the soil is unsuitable for agriculture. Scores of 2–6 indicate that soil is suitable for agriculture but with constrained productivity and severity of constraints decreasing with score. A score of 7 indicates unconstrained soil. The final measure is an average over the area of the observation.

Year of Settlement

The initial year of settlement was obtained online.[45] For the analysis, we used the earliest year listed for each colony, with the exception of New Zealand and Victoria, for which we used the year when they separated from New South Wales (1840 and 1851, respectively). Initial years for the PLSS and DLS are 1785 and 1871, respectively.

Area Governed

Area governed is measured as the land area of the territory in 1,000 square kilometers. Current boundaries of Ontario and Quebec were used to determine area for Upper and Lower Canada, respectively. Area under the DLS was calculated as the collective area of the provinces Manitoba, Saskatchewan, and Alberta. Area under the U.S. PLSS was calculated as the collective area of all U.S. states not included in our sample, with the exception of Hawaii, Texas, Louisiana, New Mexico, California, Alaska, Kentucky, West Virginia, Tennessee, and Vermont. Area for New Zealand territories was adapted from the map in Kain and Baigent (1992, p. 319, figure 8.30). Calculations of area for all other observations use current boundaries.

[43] U.S. Geological Survey, Index of /srtm/version2_1/SWBD (http://dds.cr.usgs.gov/srtm/version2_1/SWBD).

[44] International Institute for Applied Systems Analysis, Global Agro-Ecological Zones (Global-AEZ) CD-ROM FAO IIASA, 2000 (http://www.iiasa.ac.at/Research/LUC/GAEZ).

[45] British Empire: Where the Sun Never Sets, Entering and Exiting the Empire (http://www.britishempire.co.uk/timeline/colonies.htm).

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