THE DEMARCATION OF LAND: PATTERNS AND ECONOMIC EFFECTS

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Abstract. We examine the pattern of property rights demarcation in centralized and indiscriminate land survey systems and their economic effects. The dominant demarcation system through the world is an indiscriminant system referred to as metes and bounds (MB); while centralized systems tend to establish a uniform grid called a rectangular survey (RS). In the United State MB is used in the original 13 states, Kentucky, and Tennessee, as well as in the Spanish and Mexican land grants in the Southwest. The RS outlines boundaries in terms of a centrally-controlled grid of square plots. Widespread use followed the Northwest Land Ordinance of 1785 that divided federal government frontier lands into square-mile 'sections' that were further divided into smaller uniform allotments for individual claiming or purchase. We develop an economic framework for examining land demarcation systems, focusing on a comparative analysis of RS and MB. We begin by considering how a decentralized system of land claiming would generate patterns of land holdings that would be unsystematic and depend on natural topography and the characteristics of the claimant population. We then consider how a centralized system generates different ownership patterns and incentives for land use, land markets, investment, and border disputes. The rectangular survey is likely to lead to more market transactions, fewer conflicts, greater property investment, higher land values, and more infrastructure than metes and bounds. Our empirical analysis focuses on a 22-county area of Ohio where MB is used relative to the remaining 66 counties that employ RS. Our data include parcel maps, U.S. census manuscripts, court opinions, and state reports on infrastructure, legal disputes, and productivity. The results indicate that topography influences parcel shape and size under a MB system; that parcel shapes are aligned under the RS; and that the RS is associated with higher land values, more roads, more land transactions, and fewer legal disputes than MB, all else equal. It seems likely that the comparative limitations of MB contributed to long-term effects on production and land values. The results from this study also may generalize to other development settings where metes and bounds dominate

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"The beauty of the land survey…was that it made buying simple, whether by squatter, settler or speculator. The system gave every parcel of virgin ground a unique identity, beginning with the township. Within the township, the thirty-six sections were numbered …, beginning with section 1 in the north-east corner, and continuing first westward then eastward, back and forth,….And long before the United States Postal Service ever dreamed of zip codes, every one of these quarter-quarter sections had its own address, as in ¼ South-West, ¼ Section North-West, Section 8, Township 22 North, Range 4 West, Fifth Principal Meridian." Linklater (2002, 180-81).

I. INTRODUCTION

The demarcation of land is likely one of the earliest activities undertaken by humanity. Primitive societies marked and defended territories to hunting and gathering sites in order to limit open access exploitation (Bailey 1992). Early agricultural societies defined rights to much smaller plots of land for farming (Ellickson 1993). In modern societies rights are designated for residential and commercial use in dense urban areas, for farmland in highly mechanized large-scale fields, for landscapes allocated primarily as wildlife refuges or wilderness parks, and for such related resources as minerals and water. Yet, despite the somewhat obvious point that a system of demarcating rights to land will have long-term effects on land use and land, the literatures in economics and in law have not addressed these issues.

In this paper we examine the impact of two different – indiscriminate (decentralized, unsystematic) and centralized (regular, systematic) — systems of property demarcation: metes and bounds (MB) and the rectangular survey (RS). In a metes and bounds system, claimants define property boundaries by defining the perimeter of the parcel with a survey not governed by a standardized method of measurement or parcel shape. Property is demarcated by natural features of the land (e.g., trees, streams, rocks) and relatively permanent human structures (e.g., walls, markers, bridges). Under a rectangular system a large area is governed by a common system of plot shapes, sizes, alignment, and boundary descriptions for parcels.

A centralized rectangular system, however, involves initial upfront costs of delaying occupancy (or ejecting incumbent occupants) and surveying land in a uniform manner. It also forces a grid on rough terrain, raising measurement and bounding costs. We term these as coordination costs because once the RS is completed, it coordinates subsequent land allocation in a manner that provides economic benefits by reducing the marginal costs of property rights definition, enforcement, and exchange. Although MB avoids these coordination costs, the subsequent marginal costs of individual claiming, enforcing and trading property rights are likely to be higher than under RS. Boundaries are vague, imprecise, and temporary ("four paces from the most northerly rock pile, two to three oak trees…"), subject to dispute and known only to locals, creating title uncertainty and limiting the market. Further, infrastructure development, such as for roads, may be more costly because of the inexact nature and multitude of land boundaries that must be negotiated and crossed. Finally, where incongruent individual plots collide, there are gaps of unclaimed land that remain essentially open-access. As these land gaps ultimately became valued they are inevitably subject to competing and wasteful claims by the adjacent parties. For all of these reasons, the centralized system is a public good (much like a library catalog system), and capturing those gains provides incentives for use of rectangular survey where possible.

A glimpse of the potential impacts of the two systems can be seen in Figure 1which shows aerial photographs of parcel demarcated by rectangular and metes and bounds systems.[1] The land governed by the rectangular survey shows a uniform system of plots and roads, while the metes and bounds system shows a seemingly random array of plots and fewer roads.

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[1] Thrower (1966) shows similar photographs and related schematic drawings.

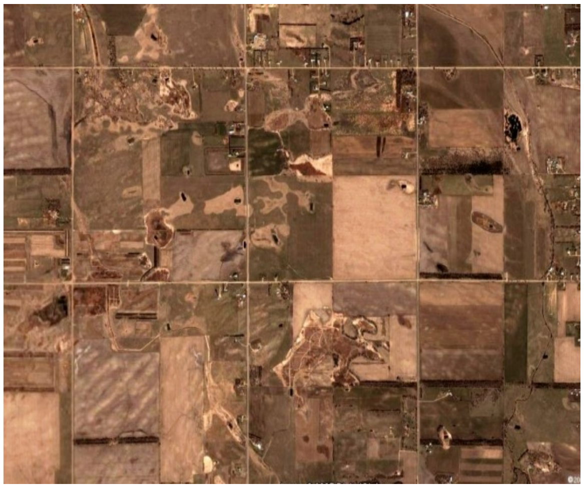 

Figure 1: Comparison of Rectangular Survey (Mitchell, South Dakota) with Metes and Bounds (Walters, Virginia)

Our analysis of the demarcation of property is part of a growing literature on the nature of property rights in contributing to different patterns of economic growth across countries.[2] Much of this literature has focused on the investment effects of differences in legal title to land, but the empirical findings have often been limited by endogeneity in the data and relatively small differences in the title systems under study. Nevertheless, there is compelling evidence for the importance of property rights on economic incentives for resource use.[3] The key empirical design issue is to define a setting for which fundamental property systems are exogenous to the agents in the data. Our empirical analysis, focused on 19th century Ohio, satisfies this requirement.

We begin in section II with a brief history of land demarcation systems, focusing on the developments in the United States. In section III we develop an economic framework for analyzing the demarcation of land under both metes and bounds and the rectangular survey, and for analyzing

[2] A large literature and cannot do justice to it…..See Besley 1995, 1998; Glaeser, La Porta, Lopez-De-Silanes, and Shleifer, 2004; Deininger 2003; La Porta, Lopez-De-Silanes, Shleifer, and Vishney, 2002; Acemoglu, Johnson, and Robinson, 2001; Bohn and Deacon 2000; Jean-Philippe Platteau, 2000; Keefer and Knack, 1995; Barro, 1991; North, 1990; de Soto, 1989; and Scully, 1988.

[3] There is a large literature on such topics as oil and gas (Libecap and Smith, 2002); forests (Bohn and Deacon 2000); American Indian Reservations (Anderson and Lueck, 1992; Anderson and Parker 2008); urban residential land development (Miceli et al. 2002); and agricultural land (Alston, et al).

the effects of the rectangular survey on land use, land markets, property disputes and public land-based infrastructure. Section IV is an empirical analysis of the implications of our model.

To summarize briefly, we find that when unconstrained by a survey system, individuals demarcated land claims in squares when the land was flat and homogeneous, but when terrain was rugged and quality varied, plots took irregular shapes based on topography. We also find that, controlling for terrain ruggedness, plot size and shape varied more with no particular alignment in metes and bounds regions than in those governed by the rectangular survey. Further, there were far fewer boundary and title conflicts under the rectangular survey than with metes and bounds. The lack of an overall framework for coordinating land demarcation, the vagueness of boundaries, and the irregular shapes of parcels were major contributors to property disputes. There were more lawyers per capita, all else equal, in MB areas than in RS regions.[4] We also find that the RS expanded the market for land, resulting in more land transactions; raised land values (by up to 30 percent); and brought more investment in roads as public infrastructure (by 17 percent), as compared to MB. We also present measures of the long-term impact of the RS. These are strong evidence of the contribution of this institutional arrangement for demarcating land.

II. A Brief History of Land Survey Systems[5]

Historically, land demarcation has been dominated by indiscriminate or unsystematic systems like metes and bounds (Brown 1995, Estopinal 1993, Gates 1968, Linklater 2002, Marschner 1960, McEntyre 1978, Price 1995, Thrower 1966).[6] While these systems vary and tend to be highly local in details, they share a method of defining land boundaries in terms of natural features of the land and relatively permanent human structures. The dominance of metes and bounds

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[4] Indeed, observation of these differences was a major reason for the adoption of the rectangular survey in Texas, which did not fall under the federal system.

[5] An extensive discussion is found in Libecap and Lueck (2008).

[6] The term 'metes and bounds' is primarily an English term though we use it to describe an decentralized, topography-based demarcation system. Geographers (e.g., Thrower 1966) use the term 'indiscriminant' survey.

suggests that there are substantive costs of establishing rectangular systems and capturing the broader gains made possible by them. In the United States MB is found in the 13 original states as well as in Hawaii, Kentucky, Tennessee, and parts of Maine, Vermont, and West Virginia. Further, metes and bounds were used where Spanish and Mexican land grants were prevalent—sections of Texas, New Mexico, California, and Arizona.[7] In California and New Mexico, the rest of those states is governed by the federal rectangular survey, a particular rectangular system. Because Texas was not carved out of federal land, in non Spanish land grant areas, the state has its own system of rectangular surveys with no meridians or baselines. Louisiana recognized early French and Spanish descriptions, particularly in the southern part of the state. Hawaii adopted a system based on the native system in place at the time of annexation.

Metes and bounds in the United States essentially ended with the enactment of the Land Ordinance of 1785.[8] The law required that the federal public domain be surveyed prior to settlement and that it follow a rectangular system as described below. Land sales were to be the primary source of revenue for the federal government, and the government bore the upfront costs of survey prior to allocation in order to provide for a uniform grid of property boundaries that were standard regardless of location and terrain.[9]

The RS was adopted by the Congress after consideration of both indiscriminate settlement and claiming under MB as was practiced extensively in the southern states and more systematic demarcation as was practiced in parts of New England under the township system.[10] RS was adopted

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[7] *Thomas Guides*, the canonical map books of Southern California, include both *rancho* and RS or Public Land Survey System (PLSS) designations.

[8] Text at http://memory.loc.gov/cgi-bin/query/r?ammem/bdsdcc:@field(DOCID+@lit(bdsdcc13201)). It was replaced by the Land Ordinance of 1787, the Northwest Odinance, that allowed for larger individual allotments. Text at http://rs6.loc.gov/cgi-bin/ampage?collId=llsl&fileName=001/llsl001.db&recNum=173

[9] Ultimately, though, homesteading and related first possession polices were used to settled much of the western federal lands governed by the rectangular survey. See Allen (1991) for an analysis of the choice between land sales and first possession policies.

[10] Treat (1910, 22-24).

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 "…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."[11] The RS applied to most of the U.S. west and north of the Ohio River and west of the Mississippi north of Texas as indicated in Figure 2. Canada adopted the rectangular survey (called the Dominion Land Survey) for parts of Ontario and the western Prairie Provinces, and it was introduced into sections of Australia, South Africa, and New Zealand (Powell 1970, Williams 1974).[12]

The American rectangular system uses a surveyed grid of meridians, baselines, townships and ranges to demarcate and describe land (Brown 1995, Estopinal 1993, Pattison 1957, Thrower 1966, White 1983, Linklater, 2002).[13] The survey begins with the establishment of an Initial Point with a precise latitude and longitude. Next, a Principle Meridian (a true north-south line) and a Baseline (an east-west line perpendicular to the meridian) are run through the Initial Point. On each side of the Principal Meridian, land is divided into square (six miles by six miles) units 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

[11] Treat (1910, 24); Burnett (1934, 563); Ford (1910, 15) in describing a letter from Governor Sharp of Maryland to Lard Baltimore in 1754, and Burnett (1934, 513) debate by New Hampshire delegates.

[12] The Romans actually extensively used a rectangular system called the *centuria quadrata* that was started in the 2nd Century BC. The Dutch also used rectangular systems in large drained areas. Both of these systems are still visible in modern Europe. Libecap and Lueck (2008) discuss these and other rectangular demarcation systems.

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

numbered 1 to 36 beginning in the northeast corner of the Township.[14] Each section can be subdivided into halves and quarters (or aliquot parts). Each quarter section of 160 acres is identified by a compass direction (NE, SE, SW, NW). Each township is identified by its relation to the Principal Meridian and Baseline.[15] In this manner, each property is positioned relative to others in a standardized way.

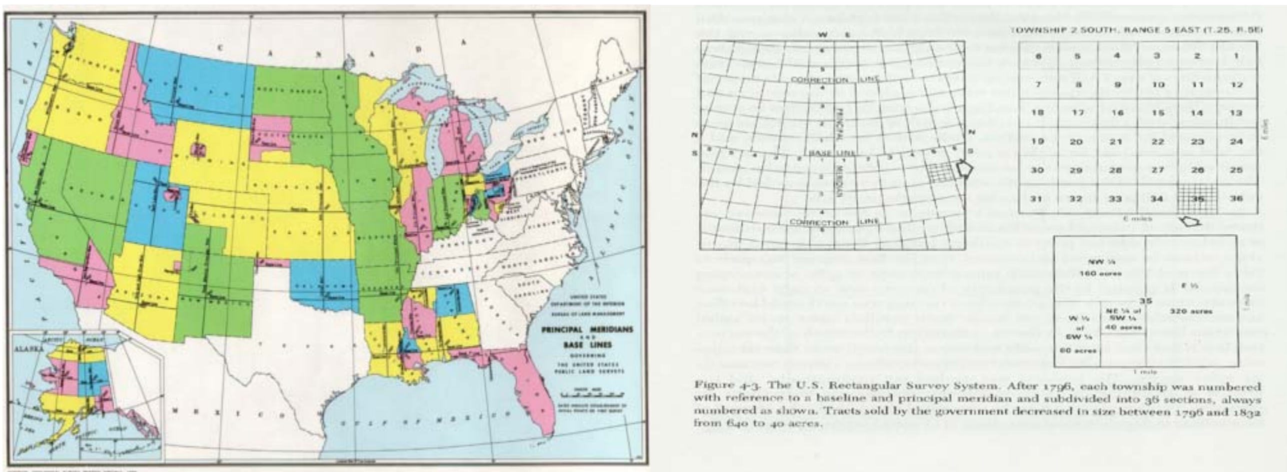

Figure 2: The Rectangular Survey System in the United States

There are 34 sets of Principal Meridians/Baselines—31 in the continental United States and 3 in Alaska, all shown in Figure 2 along with the details of the rectangular system. The Public Land Survey System began with the first survey in eastern Ohio on the Pennsylvania border at what is now called the *Point of Beginning* (Linklater 2002,71). 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. County

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[14] Some of the earliest surveys in the rectangular system had slightly different numbering systems but by the mid 1800s this system was in place (see Thrower 1966). Canada's system uses a slightly different numbering system but has 36 sections in a township (see Table 1).

15 For example, the Seventh Township north of the baseline and Third Township west of the i^{TH} Principal Meridian would be T7N, R3W, i^{TH} Principal Meridian.

lines frequently follow the survey, so there are many counties in the western two-thirds of the US that are highly linear and often rectangular.[16]

III. ECONOMICS OF LAND DEMARCATION SYSTEMS

In this section we develop an economic framework for examining land demarcation systems, focusing on a comparative analysis of the rectangular systems and metes and bounds. We begin by considering how a decentralized system of land claiming would generate patterns of land holdings that would be unsystematic and depend on natural topography and the characteristics of the claimant population. We then consider the potential gains from centralized and coordinated land demarcation system that governs are large region. In particular we examine how the rectangular survey generates different ownership patterns and incentives for land use, land markets, investment, and border disputes. In this analysis we focus on the particular features of the American rectangular system.

A. Individual Land Demarcation in a Decentralised System: Metes and Bounds

A useful way to start is to examine a case in which non-cooperative agents claim and enforce separate plots in order to maximize the value of their land, net of demarcation and enforcement costs. Consider a large tract of land available to a large group of potential claimants, where the external boundary is enforced collectively or otherwise, so that only internal and shared borders are considered by individual decision makers. Within the external borders, there is no coordination or contracting among claimants.[17]

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[16] Individual properties tend not to overlap county boundaries in order to designate administrative jurisdiction and taxing authority See (xxxx) on political jurisdictions and borders.

[17] We ignore the optimal time to claim under first possession rules which are associated with an open access resource (Lueck 1995). Similarly we assume that a claimant obtains something akin to fee simple (perpetual) ownership of the parcel and not just a one-time claim to a flow of output from the land asset. Also, it is likely that even with MB there are legal and social rules (e.g., custom, norms) enforcing the right to claim and define rights to land using geographic and topographic landmarks. So even here there is not complete decentralization but an institutional framework that support non-cooperative claiming as has been the case under most MB systems. In England and the United States, for example, the common law courts developed doctrine on claiming and border demarcation.

In this setting each potential claimant chooses the amount of acres to claim and the amount of border to enforce in order to maximize the profits net of enforcement costs.[18] Formally each claimant will solve

(1) $$\max_{a_i, p_i} V_i - y_i(a_i, p_i, t_i) - c_i(a_i, n_{i,} p_i, t_i)$$

where a_i is the area claimed (e.g., acres), p_i is the plot perimeter (e.g., miles), n_i is the number of neighbors on the plot border, t_i is a indicator of the land's topographical features (e.g., ruggedness) or land quality, $y_i(a_i, p_i, t_i)$ is the total value function that depends on the acres claimed, perimeter, and land characteristics; $c_i(a_i, p_i, n_i, t_i)$ is a border demarcation and enforcement cost function that also depends on a and p. The noncooperative Nash equilibrium solution to this problem is the optimal size (a) and perimeter (p) pair -- (a_i^*, p_i^*) -- which implies a plot shape.

Consider the simple case in which all claimants have the same productivity $(v_i = v_j, i \neq j)$ and the same enforcement costs $(c_i = c_j, i \neq j)$. In this case the problem for each party is to simply minimize the border demarcation and enforcement costs, constrained by the productivity of the land. If the land is perfectly flat these costs might simply be $c = kpa$ where k is a parameter, so the question is what shape and by implication what perimeter will minimize these costs for a give area?[19] Alternatively the question is what shape generates the largest area (and thus the lower enforcement costs per area) for a given perimeter. Put this way, the question is the ancient and famous *isoperimetric problem*.[20]

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[18] To start we lump all demarcation and enforcement costs together though in practice there are likely to be distinctions such as costs of surveying, costs of maintaining fences for livestock, costs of observing intruders, and so on. We also assume that the claims are made simultaneously rather than sequentially.

[19] Later we consider how *c* might depend on distance from a central location, on discontinuities in the perimeter, and on costs of patrolling or building on the perimeter because of topographical variation.

[20] See Dunham (1994) for history and analysis and http://en.wikipedia.org/wiki/Isoperimetry for an overview of the problem. The literature on the economics of location (e.g., Losch 1954) develops a similar model in which the land owner's objective is to minimize transportation costs to the central farm site.

The answer to this problem is that a circle will maximize the area for a given perimeter, providing the lowest perimeter to area ratio. If enforcement costs depend on the perimeter or the perimeter relative to area we should see circular plots as a Nash equilibrium. Panel A of Figure 4 shows such a pattern of land ownership for a 5 mile by 5 mile tract of land. Consider a circular plot with a 4 mile perimeter. The area will be $4/\pi = 1.27$ square miles.[21] A square parcel with a 4 mile perimeter will have an area of just 1 square mile. Panel B of Figure 4 shows the same 5 mile by 5 mile landscape with square parcels as a comparison with the circular plots.

As the discussion of circles and squares suggests, however, the enforcement cost function is likely to be more complex than simply minimizing the perimeter for a given area. First, circular plots of land are rarely observed refuting the implication.[22] Second, as Figure 4 shows circular plots leave large areas of unclaimed land.[23] In fact the unclaimed corners in circular pattern amount to about 22% of the total tract.[24] These unclaimed open access areas would not only dissipate rents derived from the land but might create locales where intruders can threaten the border of the circular plot thus adding to the costs of demarcation and enforcement. They may also lead to disputes if the land later became valuable.

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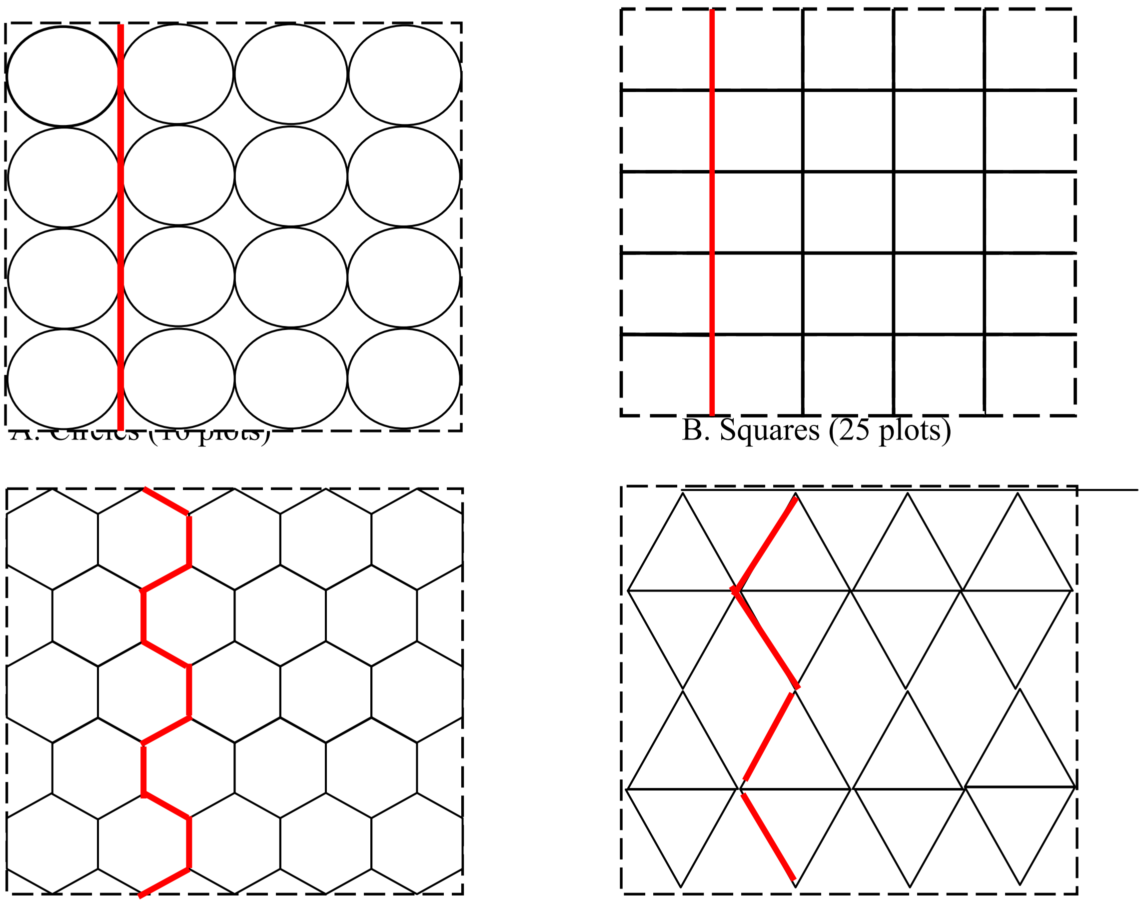
[21] The formula for the area of a circle is $a = \pi r^2$ and the perimeter is $p = 2\pi r$ where r is the radius.

[22] Circular towns, forts and villages, however are observed (e.g., Carcassonne in southern France) suggesting that a circle may indeed be optimal for the external border of a society. Circles also minimize the distance to the border from the center of the parcel. Libecap and Lueck (2008) discuss circular plots used in Cuba which created many problems of overlapping claims and boundary disputes.

[23] This is readily apparent when flying over the western US and observing circular irrigated fields within the rectangular system – the corners are dry and uncultivated (but of course not unclaimed).

[24] For a circle with a diameter of 1 mile the area is 0.785 square miles, or 21.5% less that a 1 mile square section. If you count the corners as 4 separate plots then the total perimeter of the circular plot and the corner plots is 7.142 miles compared to just 4 miles for a single square. This total is from adding the perimeter of the circle (3.142 miles) to that of the square.



A. Circles (16 plots) B. Squares (25 plots)

C. Hexagons (20 plots) D. Triangular (32 plots)

Parcel shape	*Area (A)*	*Perimeter (P)*	*P/A ratio*	*Plots in tract*	*N-S & E-W distance**
Squares	1.00 sq miles	4 miles	4.000	25	10 miles
Circles	1.27 sq miles	4 miles	3.142	16	10 miles
Hexagons	1.15 sq miles	4 miles	3.464	20	13.4 miles
Triangles	0.77 sq miles	4 miles	5.196	32	10.76 miles**

* North-south shown as red line. ** Of course the triangular system can be aligned north-south as well.

Figure 4: Possible Parcel Configurations

Given these problems with a circular landscape, we narrow the set of equilibrium parcels to regular polygons.[25] Regular polygons maximize the area enclosed by a given perimeter (Dunham

[25] A polygon is a closed figure made from line segments joined together such that each line segment intersects exactly two others. A regular polygon is a polygon with all sides the same length and all angles the same. The sum of the angles

1994) and have the potential to eliminate open access waste between parcels within a given tract.[26] In fact, there are only three regular polygons – triangles, squares, and hexagons – that will create patterns, with a common vertex, that have no interstices (space) between the parcels.[27] As suggested above a land ownership pattern comprised of contiguous regular polyhedrons would eliminate the unclaimed parcels so the equilibrium pattern will either be triangles, squares or hexagons, all of which are shown in the remaining panels of Figure 4.

The choice between triangles, squares and hexagons can be examined by further analysis of enforcement costs. The perimeter to area ratio (*p/a*) generates the following ranking from highest to lowest: hexagons, squares, triangles. The summary table in Figure 4 shows the specific ratios. The number of shared borders will likely effect enforcement costs but it is not clear how, so we cannot rank the three possible shapes.[28] Another factor is that survey and fencing costs should be lower with fewer angles and longer straight boundary stretches. This clearly favors squares over triangles and hexagons. A similar point is that a system of squares has the shortest distance across a tract for roads that follow property boundaries (see Figure 4 for the details). This leads to our first prediction.[29]

> **Prediction 1: With homogeneous (flat) land and homogeneous parties (in both productivity and enforcement ability) a decentralized metes and bounds system will yield a land ownership pattern of identical square parcels.**

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of a polygon with *n* sides, where *n* is 3 or more, is 180(*n* - 2) degrees. A triangle comprises 180 degrees, a square 360 degrees, and so on.

[26] For example, a square (a regular polygon) has the smallest perimeter to area ratio of all 4-sided polygons (i.e., rectangles).

[27] Dunham (1994, pp. 108-111) discusses the proof of this proposition and notes that the Greek scholar Pappus sought to explain the hexagon shape of bee's honeycombs in terms of maximizing the area (volume actually) for honey storage.

28 Will more neighbors mean economies of enforcement or more potential intruders?

29 If demarcation and enforcement costs are now $c = c(p/a, n)$ where $c'(n) > 0$, then a plausible Nash equilibrium in land claiming could be patterns of square parcels on a flat landscape.

This is a case where a decentralized MB system could lead to individual square plots like a RS system.

Adding heterogeneous terrain and heterogeneous claimants (either in land use or in costs of demarcation and enforcement) could yield a pattern of land ownership that would appear almost random to an aerial observer. If demarcation and enforcement costs depend on terrain (because of surveying or fencing or road building costs), we would expect borders to roughly follow the topography.[30] To take an extreme example, suppose a deep canyon cut through a fertile plateau. The cost (and benefits) of demarcating and enforcing a border across the canyon may be so excessive that the canyon edge becomes the optimal boundary. Figure 5 shows such a case where rugged topography makes linear boundaries too costly.

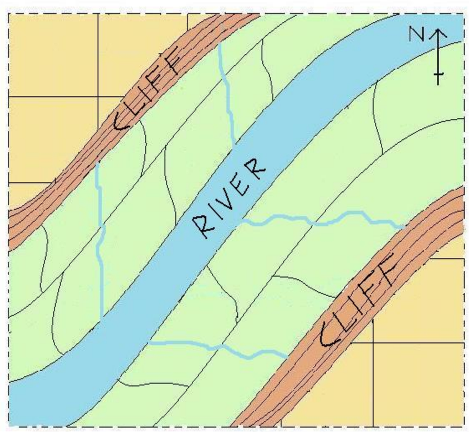

Figure 5: Decentralized Claiming in Non-planar Topography

[30] Even if costs depend linearly on perimeter, a non-planar topography will increase these costs and alter shapes and sizes. For example, consider a plot with a triangular 'valley' – 1 mile wide with a 90 angle in the bottom. Using the Pythagorean theorem ($a^2+b^2=c^2$) this adds 0.41 miles (41%) more to the perimeter. Each side of the valley is 0.707 miles long for a total of 1.414 miles compared to 1.0 mile across the plain.

The canyon itself might remain as unclaimed open access land.[31] Thus we have a second prediction

> **Prediction 2: With heterogeneous land and parties (in both productivity and enforcement ability) a decentralized metes and bounds system will yield a land ownership pattern of parcels whose borders mimic the topography and vary in size with no particular alignment.**

We thus expect the non-cooperative Nash equilibrium to yield a pattern of parcel sizes and shapes that depends on the character of the land (*e.g.,* topography, vegetation, soil and of the potential claimants (farming productivity, violence and monitoring productivity, and so on). Adding land heterogeneity (e.g., river, broken terrain) changes the cost function *c(kp,n)* and leads to non-linear claims as well as unclaimed areas -- the so-called 'gaps and gores' described by many historians of MB land systems.

B. Coordination and Collective Action in a Land Demarcation System

The previous analysis shows how land rights would be privately demarcated in an indiscriminate system with individual claiming and enforcement. It is readily apparent, however, that there are potential gains from a centralized system. First, there can be enforcement cost savings from coordinating on common borders eliminating gaps and gores. Second, and more generally, a common grid system provides information about the location of individual parcels and is thus a public good and will have greater net value if spread over a larger region. Third, coordination of survey results in similarly aligned properties and avoids the gaps of unclaimed land that arise when unsynchronized surveys collide.

Consider adjacent areas settled under metes and bounds. Even with homogeneous terrain (i.e., flat, uniform) and homogeneous claimants, however, there is no reason to expect these patterns

31 Dahlman (1980) describes the English open field system has having large acreage in 'wastes' – essentially unclaimed open access land – which were not valuable for cultivation or pasture..

of squares to be aligned in any particular direction without some sort of convention or other coordinating device.[32] Individual rectangular claims or clusters of claims could meet other competing claims at odd angles. A north-south or other similar alignment then requires either a social convention or centralized authortiy.

Figure 6 shows a case in which two sections of homogeneous flat land with square plots might have different alignments. Gaps between these claims and overlapping claims might also result from imprecision in location recording and no communication or coordination among the parties.

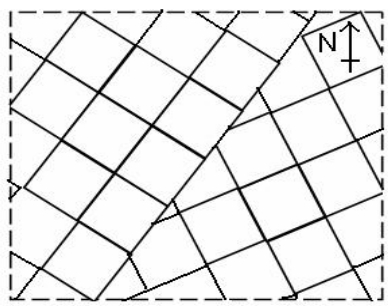

Figure 6: Claiming with Decentralized Alignment

[32] Sugden (1990) develops a theory of conventions (e.g., which side of the road to drive on) based on repeated game theory.

Finally, coordinated survey of heterogeneous land prior to allocation fixes individual land claim borders and avoids the incentives of claimants to "float" boundaries to cover the most productive land. Such opportunistic border adjustments could result in long-term border and ownership disputes among adjacent properties.[33]

C. **Land Demarcation with Centralized System: The Rectangular Survey**

Many possible centralized land demarcation systems can be imagined and some historical rectangular systems were noted above. The American rectangular survey is a particular type of centralized land demarcation system with three distinctive features. First, all land is demarcated in a system of squares (sections and township). Second, all of the squares are aligned true north, so that all borders are at a specific longitude and latitude. Third, the location of each section is part of a coordinated and systematic national system of location that does not vary by region.

In addition to these geographical and information features of the RS, the land was surveyed prior to individual ownership and use. The RS is a regime in which claiming cannot be undertaken prior to a survey and can only be made in square blocks. Not until the land is surveyed and the plots are demarcated can individual claims be made – in the U.S. this has been through purchase and through various types of first possession (i.e., homesteading) mechanisms[34].

Land claims under MB required individual surveys without the aggregate coordination benefits described above. Nevertheless, there are substantial upfront costs of providing coordinated surveys through designing the details (e.g., size of squares), implementing the survey (e.g.,

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[33] Clay and Wright (2005) describe the process of moving or floating claims to mineral land during the early California gold rush when the location of ore was uncertain. During this initial period mineral claims were uncoordinated under MB.

[32] There were of course squatters on un-surveyed federal land that were dealt with through various preemption laws. Squatting, however, was not a general characteristic of the U.S. frontier by the mid 19th century. In contrast, on the Brazilian frontier, squatting is predominant (Alston, Libecap, and Mueller 1999)

determining initial points and conducting the surveys), and controlling access until the survey was completed. Generally, because of these costs, only property owners who expected to internalize gains of the RS would adopt such a system. Their returns would accrue through the revenues of land sales to claimants who did not have bear individual survey costs and who benefitted from the other advantages of the rectangular survey. Because surveys are standardized and aligned under the RS, there are no unclaimed gaps in property claims. These factors imply another prediction:

> **Prediction 3. Larger land holders, such as the Federal Government, rural land and suburban developers or other organizations where entry can be controlled, are more likely to adopt a rectangular system.**

The effects of the rectangular survey have been discussed by historians and geographers but there is no literature on how the rectangular survey might affect incentives and thus affect such outcomes as land value, boundary disputes, land transactions, and land-based public infrastructure. The rectangular system creates linear and geographic-based borders that are fixed and thus impervious to changes in the land and verifiable using standard surveying techniques. This is a distinct difference compared to the impermanent and locally described borders in metes and bounds.

Because surveys are standardized and aligned under the RS, there are no unclaimed gaps in property claims. RS also brings coordinated survey and fixed boundaries. These factors imply another prediction.

> **Prediction 4: There will be fewer legal disputes (and litigation) over boundaries and titles under the rectangular survey than under metes and bounds**.

The rectangular system creates a public good information structure that expands the market (Linklater 2002). The impact of expanding the market and lowering transaction costs should make it cheaper for land parcels to be reorganized as market conditions change. This should be observed as a greater number of transactions such as mortgages and conveyances per unit if land. This should also increase the value of land on a per unit basis and should also lead to more uniformity in the size and shape of parcels in a region. For example, in a competitive market with access to a common technology, farms within homogeneous regions should be roughly the same size and shape.[35] Since the RS lowers the cost of transactions it will be more likely to see the result than if the original demarcation were under metes and bounds. This discussion leads to three related predictions.

Prediction 5A: There will be less variance in the size and shape of parcels under RS than MB.

Prediction 5B: There will be more land transactions under the rectangular survey than under metes and bounds.

Prediction 5C: There will be higher (per acre) land values under the rectangular survey than under metes and bounds.

The clarity and linearity of the rectangular system is also expected to have an impact on public infrastructure such as roads and other transportation systems that require long right-of-way stretches. Identification of property lines is likely to be cheaper, contiguous linear borders should lower the cost of assembling such rights of way even if eminent domain is required.[36] This implies another prediction.

Prediction 6: There will be more roads and railroads per unit of land under the rectangular system than under metes and bounds.

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[35] Even though the original plots are square consolidation under RS might lead to unusual shapes, though likely still linear since the plots can be subdivided into quarter sections and so on.

[36] To this point we have stressed the benefits of the rectangular system over metes and bounds and we have ignored the upfront costs of establishing such a centralized and systematic regime. Yet the rectangular system also has costs. In cases of rugged or extreme terrain forcing a square grid on the landscape can lead to extremely costs surveys, fence lines, and roads. Under a metes and bounds system property boundaries would tend to avoid such extreme topography thus reducing such costs. Indeed in some of the most remote and rugged parts of the western United States the most obvious components of the rectangular survey simply disappear from the landscape. For example, roads do not follow section lines but rather natural contours and in some cases only simple fences mark the property boundaries. Fields too, often lose their rectangular shape in rugged terrain. In addition, where the land use requires relatively large parcels (e.g., forests, national parks) the rectangular survey system may also lead to overinvestment in land demarcation.Note that the borders of such national parks as the Grand Canyon, Mount Ranier, and Yellowstone have linear borders even in some of the most rugged terrain.

All of these predictions will be tested in the following section using a combination of statistical data and historical accounts.

IV. EMPIRICAL ANALYSIS

In this section we test the predictions of the model against a data taken primarily from 19th century Ohio where historical events created a landscape in which metes and bounds is adjacent to the rectangular survey. We begin by describing the land demarcation systems in Ohio where both the rectangular survey was used as well as the metes and bounds in the Virginia Military District. Next we examine the demarcation of land under MB in the Virginia Military District in order to test Predictions 1 and 2 which posit a relationship between topography and parcel demarcation. Next we present a historical analysis of the adoption of large rectangular systems as a test of Prediction 3. We then examine legal disputes over property title and boundaries in the Ohio courts (Prediction 4) as well as determinants of the number of lawyers during the mid 19th century. Next we examine Predictions 5A-C which focus on the effects of land demarcation systems on land markets. The section ends with estimates of how land demarcation systems affect road construction (Prediction 6).

A. Ohio and the Virginia Military District.

Our natural experiment focuses on an area of Ohio, called the Virginia Military District (VMD). The VMD is a triangular-shaped region of 4.2 million acres lying between the Scioto and Little Miami Rivers and north of the Ohio River. Eight of Ohio’s 88 counties lie wholly within the VMD and 14 other counties are partially within it. Although subsequently made part of Ohio, the VMD was granted to Virginia to compensate its Revolutionary War veterans through issuing land warrants. The area was demarcated under metes and bounds as defined by Virginia law. The rest of Ohio, however, was demarcated under the federal rectangular survey. Hence, the land demarcation systems are exogenous for the purposes of our study.[37] Figure 7 shows the location of the VMD within Ohio and Table 1 provides comparative statistics for the VMD and surrounding counties. The sample of counties includes a county within or partially within the VMD and any counties that are directly adjacent to a county that is within or partially within the VMD. In Table 1, VMD counties are defined as counties with at least 50 percent of their area within the VMD and the remaining counties make up the surrounding counties group.

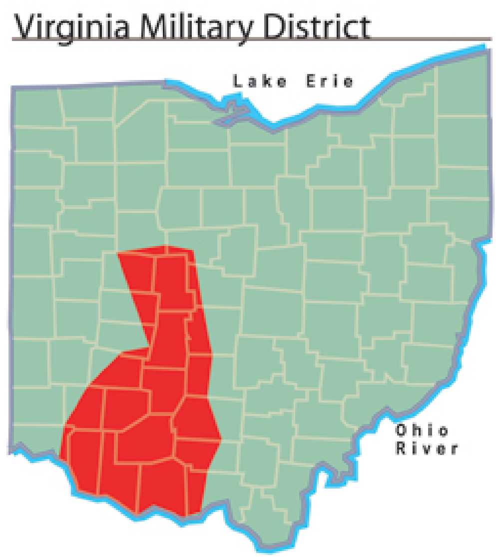

Figure 7 – The Virginia Military District

As shown in the table, the VMD counties and adjacent ones are substantially similar in their natural characteristics. The key difference for our analysis is the system under which the areas were settled and the land demarcated. In the empirical analysis that follows, we will be able to control for

[37] The cession of the VMD to Virginia too place before the Land Ordinance of 1785 and thus before the rectangular survey began in Ohio. Moreover, the territory comprising Ohio was ceded to the United States in the Treaty of Paris in 1783 and in 1787 become the Northwest Territory.

soil quality, topography, proximity to rivers, and other factors in order to investigate the impact of metes and bounds relative to the rectangular survey.

Table 1 -- A Comparison of VMD and Adjacent Counties

Characteristic	Total	VMD	Surrounding Counties
# counties	39	13	26
Average size of counties (miles^2)	468	488	458
Soil Quality (percent arable land)	78.3%	84.3%	75.3%
Terrain Ruggedness (0 = flat, 1 = vertical)	.033	.031	.034
Stream Density (Miles of Streams/sqrt(Area)	12.30	11.4	12.74

Notes: Averages are reported for county size and natural characteristics. A two-sample t-test between the groups was performed for each natural feature. In each case the mean value from the VMD counties was not statistically different from the mean of the surrounding counties (Soil Quality: t = 1.22, df = 37, P = .23; Terrain Ruggedness: t = -.32, df = 37, P = .75; Stream Density: t = -.96, df = 37, P = .34).

B. Land Claiming and Positioning under the Two Systems.

The two survey systems called for quite different land claiming and demarcation processes. Under metes and bounds within the VMD, claimants secured military warrants for various amounts of land according to rank. Once a certificate of rank and service was presented to a court of law in Virginia for authorization, a warrant was issued by the Virginia Land Office in Richmond. [38] Most warrants were subsequently sold to actual settlers or land developers and speculators. Warrant holders could claim the requisite amount of land by making an "entry" or "location" and marking its perimeter on trees and other natural or human monuments (Thrower 1966, p.43). The entry did not have to be contiguous and could be of any shape. The parcel(s) was then described in a "call" filed at the local land office, which was not necessarily in the county seat. Once the entry and call were

[38] This could be the war veteran himself or his heir or assign if he had either sold the warrant or devised it upon his death, and was probably physically located on the ground by someone designated to locate the claim on behalf of the warrant holder – typically termed an entry-man) Most warrants were sold.

recorded, the claimant hired a surveyor to survey the parcel(s) boundaries and calculate the size of the entry. Upon filing the survey at the land office, title or patent was granted to the warrant holder. There was no particular time requirement for each part of the process, and for various reasons, there often were gaps of time between each.

The survey was to conform to both the warrant and the entry description in order for the title to be valid. This conformity, however, often did not occur. One reason was that the area was a wilderness and it was difficult to locate the initial entry markings during the survey. Another was the lack of information at the time of the entry about the location of the most desirable lands. Accordingly, original boundaries often were left sufficiently vague or flexible by claimants so that they could be moved during the survey to encompass more valuable areas that had been missed. Indeed, properties could be erratically shaped by terrain and split into multiple parcels in order to use the warrant only on the best lands. These practices made boundaries much more costly to survey and mark. A third reason was due to irregularities in neighboring property boundaries that affected the perimeter of the claim.

Lacking an overall framework for positioning and demarcating properties under metes and bounds, each successive claim had to be designated or 'chained' with respect to existing adjoining property descriptions (calls), their surveys, and monuments: "Surveyed for Thomas Perkins, assignee 1,866 2/3 acres of land, on a military warrant, No 3,442, and part of 3,530, on the waters of Three Mile and Eagle creek, beginning at two lynns, a sugar tree and white oak, southwest corner of Humphrey Brooks' survey, 1,690; thence south 30 degrees west 227 poles to a white walnut, hackberry and buckeye, southwest corner of Benjamin Beasley's survey."[39] If adjacent property corners could not be verified conclusively; if that property survey were found to be faulty (covering too much land or land that did not fit the entry description); or if the surveys overlapped, then the

[39] *Nash v. Atherton* (10 O 163, 165).

entries, surveys, and titles for each of the affected, chained properties could be clouded and potentially be declared invalid by the courts because they did not conform to one another.

By contrast, under the federal rectangular survey, the land was surveyed first, marking out corners at the interval of every mile along the boundaries of the townships with monuments or notches on trees to establish the grid, as described in Section II and then opened for claiming within that structure.[40] Initially, all surveys were to be done by surveyors hired by the Geographer of the United States.[41] Individual purchasers could divide the grid into subplots of one mile square. At the local land office, they confirmed that the land of interest had not already been entered by another, filed their entry and hired a licensed surveyor to mark internal boundaries. Once this process was completed, they could purchase the land from the government and receive title.

This coordinating institution anchored each property according to the federal land survey and assigned its location within a specific section, township and range, such as a sixty-acre tract in "…. the west half of section 13, T[ownship] 3, R[ange] 4, east of M.D" or a thirty-acre tract at "R[ange] 4, T[ownship] 3, S[ection] 13, p. N.…"[42] As a result, within the rectangular survey it was unnecessary to define a land holding relative to neighboring properties. Further, all lands within the specified parcel were included, regardless of quality. It was not possible to gerrymander the claim under the RS as was done under MB. Accordingly, individual survey costs likely were reduced under the RS and boundaries and titles were more definite than under MB. We examine differences in boundary/title conflicts between the RS and MB below.

C. The Shape of Parcels in the Virginia Military District

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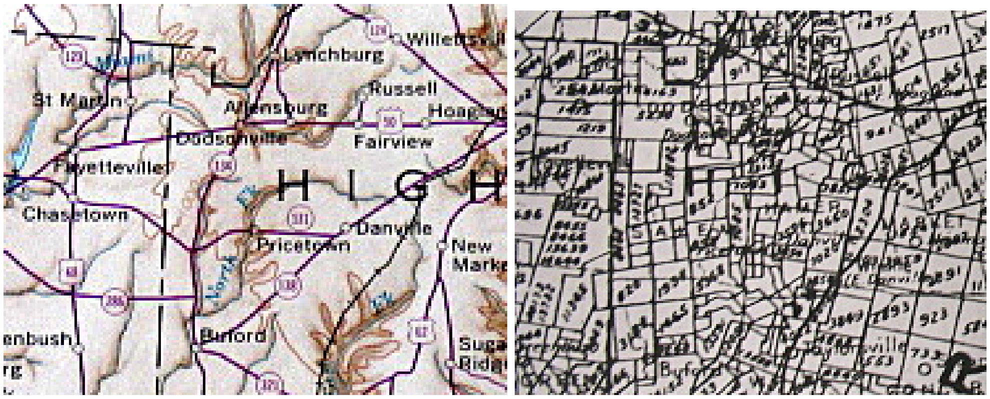
[40] Pattison (1957, 159, 164)
[41] White, 1983, 14).
[42] *Treon's Lessee v. Emerick* (6 O 391, 392). See also Linklater, 2002, 181: "¼ South-West, ¼ Section North-West, Section 8 Township 22 North, Range 4 West, Fifth Principal Meridian;" Trower 1966, 37: "Township 2 S Range XE Section 2 E ½ NE acres W ½ NE 159.44…"; Peters, 1930, 102: "Lot No. 5 of the east half of the southeast quarter section 4, town [ship] 5, range 14 of the Ohio River Survey"; 6 O 391 *Treon's Lessee v. Emerick*.

Individuals had the flexibility under metes and bounds to determine the shape and size of their properties. The model of land demarcation developed in Section III predicts that under MB the demarcation of parcels will depend on the topography of the land. In relatively flat, homogeneous terrain we predict squares, and in relatively rugged terrain, where land is heterogeneous we predict that the parcel shapes will follow local features, such as ridges and rivers that influence the costs of demarcation and the productivity of the land. We test these predictions by examining the relationship between the topography of the land and the size and shape of the original parcels in the VMD.

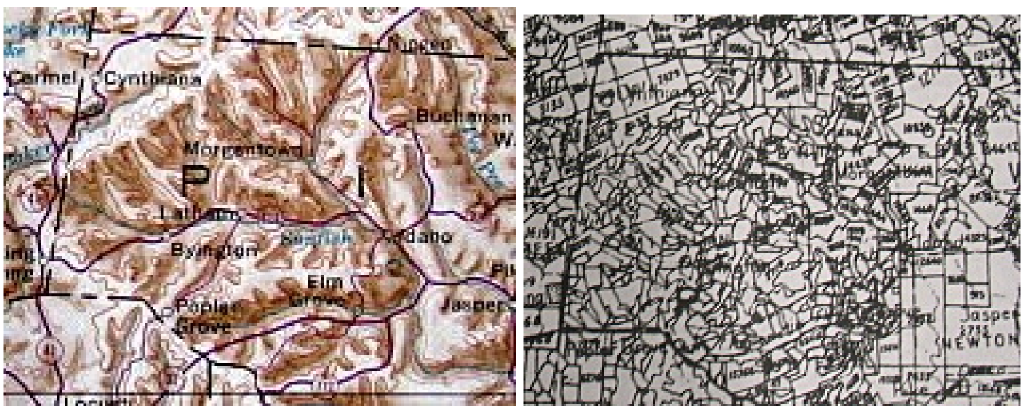
We begin the analysis with visual inspection of topography and parcel size and shape within the central VMD. Figure 8, Panel A shows a section of flat land in Highland and Clermont counties.[43] It is evident that the parcels are rectangular and even square as predicted. In the VMD there were large sections of land that had been assembled by speculators who purchased warrants from veterans. The pattern shows evidence of coordinated surveying, where groups of tracts are aligned in the same directions, but not typically north-south as in the RS. This pattern is consistent with Prediction 3 regarding the incentives to provide systematic survey that existed when large tracts of land were owned. Because we do not have original ownership information, we cannot directly test the prediction for the VMD. We return to this issue later in the paper with evidence for elsewhere in the U.S.

In contrast Panel B shows a similarly sized area in Pike County (eastern VMD) where the terrain is more rugged.[44] Here the parcels tend to have much more variation in parcel shape and size, with the boundaries often following land contours and other natural features. There is no evidence of coordinated parcel boundary alignment in some areas as seen in Panel A.

[43] Ruggedness equals .027 for Highland and .034 for Clermont.
[44] Ruggedness equals .088.



Panel A -- Parcel boundaries in flat topography (Highland and Clermont counties)



Panel B -- Parcel boundaries in rugged topography (Pike County)

Figure 8. Visual correlation between topography and original VMD parcel demarcation

In order to quantify and analyze the variation in parcel shape, size, and alignment under MB and RS, we have digitized a map of *all* land parcels in Ohio in 1853, and calculated area, perimeter, perimeter-area ratio, number of sides, angle deviations, and alignment for each parcel.[45] We also have topography and soil quality by parcel.[46] The perimeter-area ratio variable (*p/a*) reflects how

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[45] The data come from maps in Sherman (1922) as digitized by McDonald et al. (2006).Normally the square root of area is used to ensure that the numerator and denominator are both measured in the same units (Longley et al. 2005). These measures are likely linked to the costs of demarcation and are ways to quantify the size and shape of parcels.

[46]To measure topography we use 1 arc-second (approximate cell size of 30x30m^2) digital elevation models (DEMs) from the USGS National Elevation Dataset to calculate slope angles for each cell of the DEM. Slope angles were averaged at the county and township levels and then divided by 90 to create a "ruggedness" index from 0-1.

efficiently a boundary defines a specific area requirement. As described in Section III, the ratio has a value of four for a square (our reference shape), thus the closer the value to four, the more square the parcel. Additionally, the number of sides indicates regular is the parcel shape and how it deviates from a square.[47]

Our model predicts that parcel shape will tend to deviate more from a square, adding more sides, and that the perimeter-area ratio will become larger as the land becomes more rugged. We test predictions 1 and 2 by estimating the average perimeter-area ratio and the average number of parcel sides for parcels in each township on topography (average township ruggedness).[48] Only townships with more than half their area within the VMD were used in the analysis (n = 194). The results are presented in Table 2.

Table 2 -- Topography and Parcel Shape

INDEPENDENT VARIABLES	(1) Average Perimeter-Area Ratio of Parcels	(2) Average Number of Parcel Sides
RUGGEDNESS	6.219***	25.45***
	[0.537]	[2.114]
CONSTANT	4.572***	5.638***
	[0.0285]	[0.112]
Observations	153	153
R^2	0.471	0.490
F-Statistic	134.3	144.9

Notes: Results are reported from weighted regression models of parcel shape characteristics. The dependent variables are labeled at the top of each column. The parameter estimates for the independent variables are reported with their standard errors listed below in brackets (*** p<0.01, ** p<0.05, * p<0.1). Observations were weighted by the number of parcels in a township. When using standard errors that are corrected for spatial dependence (not reported) significance levels of the independent variables do not change.

[47] For highly organic shapes, geographic information systems represent the "squiggly" lines as many smooth sides, thus the higher the number of sides, the more organic (naturally linked to topography) the parcel shape.

[48] In the empirical models in this paper, it is likely that the error terms are correlated with error terms of nearby observations, potentially making the typical OLS formulas for inference unreliable. To account for spatially-correlated unobserved forces acting on the dependent variables, we evaluate both typical OLS standard errors and standard errors that are corrected for spatial dependence. The spatially adjusted standard errors referred to in this paper follow Conley's (1999) cross-sectional model which corrects for spatial dependence of an unknown form. This model assumes that spatial dependence will decline as the distances between observations increases. Without having information on the nature and potential causes of spatial correlation in our study, Conley's spatial error model appears most appropriate.

As shown in both specifications, terrain ruggedness has a statistically significant positive effect on the average perimeter-area ratio and number of sides of a parcel. These results suggest that property boundaries increasingly conform to topography as the terrain becomes more rugged, leading to more irregular parcel boundaries, a higher perimeter-area ratio, and more sides under uncoordinated land claiming and surveying within the VMD.

The average perimeter ratio for parcels within the VMD is about 4.6. An increase of one standard deviation in terrain ruggedness increases the parcel perimeter-area ratio by .18. To add context to this magnitude, .18 is roughly the difference between the perimeter-area ratio of Colorado (4.05) and the perimeter-area ratio of New Mexico (4.24). The average parcel in our sample has approximately two more sides than a square parcel. The model results indicate that for each 1.4 standard deviation increase in terrain ruggedness, the expected number of sides for VMD parcels increases by 1.

D. Alignment of Parcels in the VMD and Ohio.

There was no mechanism under MB to coordinate boundary alignment as was the case with the RS. Even where some properties appear to be aligned as indicated in Figure 8, Panel A, whenever groups of coordinated parcels abutted one another, the configurations clashed (see also Figure 6). The result was triangular sections that often were unusable for agricultural production and unclaimed originally.[49] Indeed, the major scholar of Ohio lands, William Peters (1930, 30, 135) pointed to the many gaps of vacant land found in the VMD. He noted that by 1852 when all military warrants had been used for land claiming, 76,735 acres of land remained unclaimed. To find some legal use of the properties, An Act of Congress transferred unlocated and unsurveyed land in the VMD to the state of Ohio in 1871.

[49] Footnote the ag production/engineering stuff here and probably address it again in the value section as well.

Our theoretical discussion of land demarcation under MB argued that there was no reason to expect a particular directional alignment of parcels even when the land was flat and squares were chosen. In particular, we would not expect that the parcels will be aligned north-south as in the federal RS. We also expect rugged terrain to increase the costs of the RS and to potentially disrupt its systematic alignment, but not as much as in MB areas where there was no overall coordination framework.

To test these predictions, we estimated the standard deviation of parcels' alignment within a township for all townships in Ohio against independent variables for the percentage of a township's area within the VMD, the ruggedness of the terrain within the township, and an interaction between these two variables. We estimated the equation below

(2) $\textit{Std Deviation of Alignment} = \alpha + \beta_1 \textit{VMD} + \beta_2 \textit{Ruggedness} + \beta_3(\textit{VMD} * \textit{Ruggedness})$

Alignment is measured as the angle of orientation of the longest side of the parcel, measured in degrees, for all original Ohio parcels.[50] The interaction term was included to isolate the effect of terrain on the alignment under RS. As in the parcel shape models, observations are weighted by the number of parcels in the township. We expect that parcels under a decentralized metes and bounds system to have larger variation in parcel alignment and that more rugged topography will increase demarcation costs and obstruct systematic alignment in both arrangements, but more so under MB.

Due to the difficulty of interpreting interactions of continuous variables, the model was run three times with the independent variables "centered" at meaningful values for interpretation (See Appendix for more detail). Model 1 represents the variables in their original state. In Model 2 the ruggedness variable is centered about its mean, by subtracting its mean value from each observation.

[50] Data sources

In Model 3 percent area in the VMD is subtracted by 1 (i.e. 100% inside the VMD = 0). Results are reported in Table 3.[51]

Table 3 - Alignment of Parcels under Metes and Bounds and the Rectangular Survey and the Impact of Terrain Ruggedness

Independent Variables	STANDARD DEVIATION OF ALIGNMENT		
	(1)	(2)	(3)
% AREA IN VMD	9.171***	10.10***	9.171***
	[0.319]	[0.227]	[0.319]
RUGGEDNESS	5.421***	5.421***	29.36***
	[1.907]	[1.907]	[4.700]
INTERACTION	23.94***	23.94***	23.94***
	[5.084]	[5.084]	[5.084]
Constant	1.111***	1.322***	10.28***
	[0.101]	[0.0705]	[0.301]
Observations (townships)	1353	1353	1353
R-squared	0.613	0.613	0.613
F Statistic	711.5	711.5	711.5

Notes: Results are reported from weighted regression model of parcel alignment within a township. The parameter estimates for the independent variables are reported with their standard errors listed below in brackets (*** p<0.01, ** p<0.05, * p<0.1). In Model 2, the ruggedness variable is centered about its mean. In Model 3, the VMD variable was reduced by one so that 100% within the VMD corresponds to a zero value. Observations were weighted by the number of parcels in a township. When using standard errors that are corrected for spatial dependence (not reported) significance levels of the independent variables do not change.

The interaction term between proportion of area within the VMD and the ruggedness of the terrain is statistically significant at the 1% level. The coefficient on the VMD variable shows a positive effect at the 1% significance level on the standard deviation of parcel alignment in all models. The results from Model 1 indicate that under completely flat terrain (i.e. ruggedness = 0), a change to an RS system from MB reduces the dependent variable by about 2.2 standard deviations. In terrain with average ruggedness (Model 2), the dependent variable is reduced by about 2.5 standard deviations from a change to RS. The sizable reductions in parcel alignment deviation illustrate the lack of parcel coordination that exists without a centrally planned survey system.

[51] In the first two models the ruggedness coefficient reflects the impact in the RS. In Model 3 the VMD becomes the zero value. In this model the ruggedness coefficient represents the impact in the VMD. As we have argued, under individual claiming under MB, there is no central coordination. With topography influencing the costs of demarcation, we would expect increasingly rugged topography to dominate demarcation patterns where there is no central plan.

By setting the VMD variable equal to zero in Model 1, we see that terrain ruggedness has a statistically positive effect on the standard deviation of parcel alignment in RS townships. A one standard deviation increase in ruggedness increases the dependent variable by .11 standard deviations. [52] Although somewhat modest in magnitude, the significantly positive relationship provides evidence that rugged terrain can prevent obstacles to the systematic RS system by increasing the costs of survey. As expected, the magnitude of the ruggedness variable in Model 3 is substantially larger than the first two models. This further illustrates the large role topography plays in boundary demarcation in an MB system.

E. Large Land Owners and Incentives to adopt the Rectangular Survey.

Prediction 3 states that large landowners or sovereigns are more likely to adopt a centralize rectangular system. We have argued that the RS provides the public goods of systematic location of properties, coordinated survey, reduced title conflict and greater infrastructure investment. We also noted that there were higher upfront costs associated with the RS than the MB. These notions suggest that the RS would be used only when these benefits could be internalized to offset the costs of systematic survey. Governments, large land grantees or land speculators who planned to subsequently subdivide and sell, as well as suburban real estate developers are examples of cases where the RS would be used. These owners would capture the resulting higher land values.

As noted above, there is considerable historical evidence that Thomas Jefferson and others in the Continental Congress pushed for the establishment of the rectangular survey because they were frustrated with the metes and bounds system and expected a positive impact on land values that would raise federal revenues from land sales.[53] Jefferson was head of a committee of the Continental Congress organized to choose the best way to survey and sell land. The pervasive Virginia method

[52] Calculated by multiplying the standard deviation of ruggedness by its coefficient in Model 1 and then dividing by the standard deviation of the dependent variable (standard deviation of alignment) when under the RS.
[53] Ford (1910, 55); Treat (1910, 16); Pattison (1957, 87), Webster (1791, 493-95); White (1983, 9).

allowed claimants to choose their property, survey by metes and bounds, and then purchase it. This was ruled out by the committee, which instead called for survey before occupation with properties to be marked in squares, aligned with each other, "so that no land would be left vacant," to prevent overlapping claims, and to simplify registering deeds.[54] Under this approach the U.S. could sell land to raise money and would have the system "decimalized."[55] Squares also reduced survey costs because only two sides of each township and smaller parcel had to be surveyed.[56] Hamilton stressed the importance of land sales for the U.S. Treasury and supported Jefferson: "The public lands should continue to be surveyed and laid out as a grid before they were sold." Prior survey was also seen as a means generating information about the value of federal lands before sale: "It was pointed out that congressional surveys would disclose a great deal of valuable information concerning the western lands."[57] For all of these reasons, Jefferson's recommendation became incorporated in the Land Ordinance of May 20, 1785 for disposing lands in the western territory.[58]

Although metes and bounds were common in New York state, in northwestern New York, large tracts of land purchased from the Iroquois by land developers who also secured other large military tracts who then divided the areas into townships to be surveyed before sale. In subdivisions, such as Cooper's tract, a rectangular grid was used dividing the lands into 100 square lots of up to 600 acres each.[59] The Ohio Company of Associates secured 1,000,000 acres of land divided into townships 6 miles square from the federal government in 1787 and followed the same procedures as the government in surveying and selling the property.[60]

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[54] Linklater (2002, 68-70); White (1983, 9).
[55] Linklater (2002, 68-70)
[56] Burnett (1934, 563).
[57] Taylor (1922, 12).
[58] Linklater (2002, 116, 117).
[59] Price (1995, 232-6).
[60] Linklater (2002, 81).

Finally, urban areas developed under land grants or subdivisions, like Philadelphia, Charleston, and New York were placed into grids to promote commercial activity.[61] By contrast, Washington D.C., which was supposed to be a city of political administration, rather than of commerce, was designed with stars and circles.[62]

F. Property Disputes under the Two Demarcation Systems.

We see that controlling for terrain, properties demarcated under MB have greater variation in shape, size, and alignment than those demarcated under RS. These conditions and the claiming process described above suggests that there would be more legal disputes over property boundaries and titles under MB than under RS (prediction 4). Our empirical analysis uses both historical accounts and case law in the Ohio courts during the 19th century.[63] Moreover, the record of conflict in the VMD illustrates the fundamental coordination problems facing land claimants under a metes and bounds system that were addressed by the rectangular survey.

Historical Accounts.

The literature on metes and bounds repeatedly references conflicts over boundaries and titles. Richard Anderson, who was a surveyor of military bounty or warrant lands in the VMD and Kentucky in the late 18th and early 19th centuries, commented that the practice of using 'perishable' or moveable landmarks such as trees and stones, allowed settlers to pick and chose the best land by adjusting the markers as necessary, often creating multiple claims to the same property and inviting disputes.[64] In his examination of Ohio lands, William Peters (1930, 26, 30, 135) concluded that there was more litigation due to overlapping entries, uncertainty of location, unreliable local property markers, and confusion of ownership in the 19th century in the VMD than in the rest of Ohio

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[61] Ford (1910, 13)
[62] Linklater (2002, 187).
[63] *Ohio Jurisprudence: A Complete Statement of the Law and Practice of the State of Ohio*, Willis A. Estrich, editor, vol 32, Rochester New York: The Lawyers Cooperative Publishing Company, 1934, 749-839 plus others….
[64] http://www.library.uiuc.edu/ihx/rcanderson.htm, Richard Clough Anderson Papers, University of Illinois Library.

combined. To quiet titles and to reduce litigation, Congress was repeatedly involved in Virginia Military District issues: "In 1855, one congressman estimated that Congress had passed some forty-four acts dealing with the affairs of the Virginia Military District because, despite its origin as a state project, it soon became part of national public lands administration."[65]

More broadly, in discussing the congressional debate in 1785 over the type of survey system to adopt in the new land ordinance, even southern delegates supported RS because of "the thousands of boundary disputes in the courts" under MB in the South (White, 1983, 9). In a study of metes and bounds in the eastern U.S. Francis Marschner (1960, 1, 39) stated that 'uncertain boundaries' brought disputes over conflicting holdings that required special courts to resolve. Similarly, in an analysis of the early U.S. rectangular survey William Pattison (1960, 231) conjectured that there were more lawsuits under metes and bounds system than with rectangular grid. Indeed, Edward Price (1995, 310-11) claimed that after observing the confusion and associated court challenges over land boundaries in the metes and bounds states of Kentucky and Tennessee, Stephen Austin implemented a local rectangular survey system in the new republic of Texas. As a result: "Texas avoided the litigation-haunted metes and bounds system that dogged other southern states."[66]

Under MB, it was common for duplicate land entries to be made. Because there was no requirement that a claim be registered with the county in which it was located, only with the local land office, notice of an existing entry was difficult to obtain. Additionally, it was not uncommon for a survey registered with the local land office to have property descriptions that were too unclear for a succeeding claimant to know exactly where the property was situated in order to locate around it. Indeed, William Hutchinson (1927, 117) and Asa Rubenstein (1986, 240) described a practice of surveyors in the VMD and Kentucky of recording claims very broadly and vaguely in an effort to

[65] Taken from James W. Oberly, *Sixty Million Acre* as quoted in the Richard Clough Anderson papers, University of Illinois Library, http://www.library.uiuc.edu/ihx/rcanderson.htm.
[66] Andro Linklater (2002, 241)

preempt later claimants, who would be challenged with assertions of superior equitable title.[67] Survey costs for subsequent parties were increased by the numerous small parcels and irregular shapes of the claims made by those who came before them: "But a boundary good for one selection was not necessarily good for the next tract, and the selections of earlier settlers might leave large areas of undesirable land in awkward shapes for later comers."[68]

Ohio Court Opinions

The Ohio courts repeatedly noted the difficulty of titles in the Virginia Military District. A typical comment is found in a 1840 property dispute from Brown County in *Nash v. Atherton* (10 O 163, 167): "This case involves principles which are important, and upon its correct decision must depend in some measure the security of titles within the Virginia military district, which at the best, have been heretofore considered as somewhat precarious, and have been, and still continue to be, subject to much litigation."[69] Indistinct property boundaries resulted in competing land claims. For example in an 1827 boundary case from Warren County, *McCoy's Lessee v. Galloway* (3O 282), adjacent entries covered the same land. The dispute centered on the plaintiff's corner monuments, which the court found to be too indefinite to support: "They cannot change a sugar-tree to a hickory, or an ash to a beech."[70]

To designate property for titling under metes and bounds and to inform subsequent locators so that they could make their own claims with respect to the property's boundaries, Ohio law

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[67] Asa Lee Rubenstein, *Richard Clough Anderson, Nathaniel Massie, and the Impact of Government on Western Land Speculation and Settlement, 1774-1830*, University of Illinois, dissertation, 1986, p. 240; William Thomas Hutchinson,, *The Bounty Lands of the American Revolution in Ohio*, University of Chicago, dissertation, 1927. p. 117. Similar to submarine patents—get references.

[68] Price (1995, 21) see also pp, 89, 145.

[69] See also *Porter v Robb* (7 O (Pt 1) 206, 210-211): "To relieve would shake more than half the titles between the Scioto and Little Miami rivers….;" and *Lessee of Cadwallader Wallace v Richard Seymour and H. Rennick* (7 O 156, 158): "…a variety of questions are presented of more than ordinary difficulty, in consequence of the nature of the titles in the Virginia military district…".

[70] See case discussion in Page, 1936, Vol 12 (1), 83. Similarly, in *Nash v. Atherton* (10 O 163) a misreading of corner boundaries of an adjacent survey led the plaintiff and defendant to make overlying land claims.

required that borders be defined clearly with corner monuments, which could be natural or artificial; the direction or courses be described precisely; and the distances involved measured accurately. For example, consider the court's comments in an 1835 case from Clermont County of *Porter v Robb* (7 O (Pt 1) 206). In locating a parcel a warrant holder "… is required to make his location or entry 'so specially and precisely as that others may be enabled with certainty to locate other warrants on the adjacent residuum.'"[71] The entry filed at the land office served as formal notice, withdrawing the land from claiming by others: "After an entry is made, others examine it, ascertain what land is called for, and locate in the neighborhood of and adjoining it."[72] The survey was to be consistent with the entry.[73] Failure to follow these steps could lead to rejection of the claim by the court: "a vague and uncertain entry of a Virginia military warrant is void..."[74] If the description and boundary markers were not recognized, the entry and survey might be ruled invalid: "The calls in an entry must have acquired notoriety at the time of the location, otherwise the entry is void" and "A survey…cannot aid a defective entry…"[75]

Unfortunately, because properties in the Virginia Military District were delineated with respect to one another, voiding one title could lead an entire chain of land entries to be defective. In *Porter v. Robb* (7 O (Pt 1) 206, 211) a series of entries were surveyed by the same individual, defined relative to one another, and vulnerable to mistakes or opportunism in any one of them:

> "….Stephenson's entry calls for the upper line of Dandridge; Waters' calls for the upper line of Stephenson; Crawford's for that which is the north line of Waters'….. The return of the county surveyor shows that Dandridge's upper line is twenty poles too far up the creek. It is four hundred and twenty poles from the base, whereas it should have been but four hundred. This twenty poles is on

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[71] *Porter v. Robb* 7 O (Pt 1) 206, 209; *McArthur v. Nevill* (3 O 178) as noted in Walker and Bates, 1875, 1304: "A valid entry must be certain and precise, and must contain the means of ascertaining its boundaries, in order that others may locate the adjoining land with safety."
[72] *Porter v. Robb* (7 O (Pt 1) 206, 209).
[73] *Porter v. Robb* (7 O (Pt 1) 206, 210).
[74] *Martin v. Boon* (2 O 237) as discussed in Laning 1906, 13299.
[75] *Martin v. Boon* (2 O 237) as discussed in Laning 1906, 13299 and *Lindsey v. Miller* (1O.F.D. 428) in Laning, 1906, 13300. See also *Kerr v. Mack* (1 O 161) in Laning 1906, 13300.

> Stephenson's entry. Obannon, in surveying for Stephenson, took this line, as run by him for Dandridge, as the lower line of Stephenson. This threw Stephenson twenty poles on Waters' entry. As Stephenson has a larger entry than Dandridge, and probably a proportionate surplus, it is then probable that his survey encroached at least forty poles upon Waters' entry. This caused Crawford, by having to begin at a corner of Waters', to be thrown a considerable distance farther from the Ohio than he would have been had there been no mistake made by Obannon in making his chain of surveys."

Because of these linkages, the court called for definite boundaries, rejecting the common practice of adding an adjustment factor to each survey line: "Where a chain of entries of land in the Virginia military district are made dependent upon each other, each calling for a line of a specified distance and the next commencing at the termination of that distance, the actual location of each must be ascertained by measuring the number of poles called for in the entry. An extension of these distances is not allowable upon an alleged custom of extending at a distance of five percent."[76]

Property conflicts under metes and bounds could linger for long periods of time with uncertain title. For example, in *Kerr and Others v. Mack* [77] the Ohio Supreme Court ruled on conflicting surveys in Adams County that began in 1792 and continued until the court's ruling. Kerr charged that Mack's survey was so vague and uncertain that he "did not know where it was intended to lie." Similarly in *Morrison v. Balkins* (6 Ohio Dec. Reprint 882), the Court of Common Pleas, Hardin County in the VMD, in 1880 ruled on an effort to quiet title to some 120,000 acres of unpatented lands, occupied for over 21 years by parties who could not trace title to the original holders.[78]

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[76] *Andrew Huston v Duncan McArthur*, 7 O pt. 2, 54, 55
[77] 1 Ohio 161, Ohio Lexis, December 1823
[78] 6 Ohio Dec. Reprint 882

Analysis of Ohio Court Cases.

To more systematically examine the prediction of excessive litigation over property in metes and bounds counties, we searched compendiums of Ohio court cases in the 19th century and then turned to Westlaw and Lexus/Nexus for case reports.[79] The cases considered are those argued before the Ohio Supreme Court, meaning that most conflicts presented before the lower Courts of Common Pleas, unfortunately, are not included in the analysis. Nevertheless, the Supreme Court cases appear consistent with the qualitative discussions presented above. Table 4 summaries the results of the analysis.

Table 4 - 19th Century Ohio Supreme Court Property Disputes, VMD and Rest of Ohio

VMD			Non-VMD		
Total Number of Cases		86	Total Number of Cases		44
Boundary Dispute?	Validity of Entry/ Patent?	Validity of Survey?	Boundary Dispute?	Validity of Entry/ Patent?	Validity of Survey?
10	59	17	23	16	5

As the data in Table 4 show, there are nearly twice as many Supreme Court property boundary, survey, title cases in the Virginia Military District as in the rest of Ohio, a finding consistent with the qualitative literature. In RS regions of Ohio, 45 percent of the cases involved boundary disputes; 31 percent concerned the validity of title; and 10 percent contained survey issues. The boundary dispute cases in non-VMD areas seem to be more typical adverse possession cases – they generally involved a dispute between adjacent landowners over a small strip of land located

[79] *Page's Ohio Digest: A Digest of All Reported Decisions of the Courts of Ohio from the Earliest Period to Date*, John L. Mason Editor in Chief, Volume One, Part One, Abandonment to Assault and Battery; Part Two, Assignments to Charities, Volume Four, Deeds to Equity, Volume Eight, Subrogation to Youthful Employee, Cincinnati: The W.H. Anderson Company, 1914; *A Digest of All Reported Decisions of the Courts of Ohio from the Earliest Period to Date*, Lifetime Edition, edited by William Herbert Page, Volume 10, Parties to Receipts, Volume Twelve, Part One, Taxation to Venditioni Exponas, Cincinnati: W.H. Anderson Company, 1936. *Ohio Jurisprudence: A Complete Statement of the Law and Practice of the State of Ohio with Forms*, Editor in Chief: Willis A. Estrich, Consulting Editor William M. McKinney, Managing Editor, George S. Gulick, Volume 1 (1928), Historical Introduction to Adverse Possession; Volume 5, Bail to Boundaries (1929), Volume 15 (1931), Easements to Encumbrance, Volume 32 (1934); Pledges to Public Schools, Volume 39 (1935), Taxpayers' Actions to Trial, Rochester, New York: The Lawyers Co-operative Publishing Company. The Lexis/Nexis search used terms: boundary, quiet title, trespass, and ejectment.

along their common property boundary. The validity of title cases in non-VMD areas generally involved failure to comply with some procedural requirement involved in obtaining a patent or filing with county recorders or land offices under the RS. The small number of survey cases reflected the requirement that surveys follow section lines; that parcels be squares; and the use of government-hired surveyors to lay out sections, townships, and ranges in the grid prior to entry under the provisions of the federal land law. This provision appears to have reduced error and the associated opportunistic use of surveys by claimants that was prevalent under metes and bounds. For example, the court in *Walsh's Lessee v Ringer* (2 O 327, Page Vol 12, pt 1, 82) the court pointed to simplicity with the rectangular system: conveyance of 70 acres "in the southwest corner of a particular tract is a conveyance of so many acres lying in a square in said corner."

In contrast, in the VMD, 81 percent of the cases involved a challenge to the validity of the entry or patent; 24 percent concerned disputes over the validity of survey; and 14 percent covered boundary disputes. A reading of the cases indicates, however, that there was considerable overlap among these categories in VMD cases, with boundary, survey, and title conflicts inextricably intertwined.

Number of Lawyers per Capita.

Because agricultural land was the most valuable asset in 19th century Ohio and because there was more litigation over land boundaries and titles under MB than under RS, a related prediction is that we expect there to be more lawyers per capita in VMD counties than elsewhere in the state. To test for that possibility we estimated the number of lawyers and judges in 1880/divided by county population against a variety of control variables, as well as percent of county area in the VMD.[80]

[80] Number of lawyers from the 1880 U.S. Population Census as provided by Joe Ferrie, Department of Economics, Northwestern University **other data sources.

These estimates are reported in Table 5 and as indicated, there were more lawyers and judges per capita in VMD counties than in other Ohio counties, all else equal.

Table 5 - Number of Lawyers Per Capita in the VMD relative to Surrounding Counties

Independent Variables	Percentage of Lawyers per Capita
% AREA IN VMD	0.528**
	[0.218]
POPULATION DENSITY	0.0200***
	[0.000607]
PERCENT FARMLAND	2.357*
	[1.364]
MANUFACTURING UNITS PER 1000 PEOPLE	-0.0465
	[0.0549]
CONSTANT	-2.562*
	[1.283]
Observations (counties)	39
R-squared	0.994
F Statistic	1414

G. The Market for Land in the VMD and Elsewhere in Ohio.

Our model of land demarcation under the rectangular survey generates several predictions about the market for land (Predictions 5A-C). A major way in which the RS may have raised land values was to expand the market by providing precise locations and property boundaries that did not rely upon idiosyncratic markers that would be understood only by local transactors. As noted by Linklater (2002, 80), the advantages were clear as demonstrated by the first patent issued at the New York City Land Office, March 4, 1788. In that patent, John Martin paid $640 for a square mile section in NW territory (Belmont County, Ohio), Lot 20 Township 7, Range 4. Although it was in the frontier, "once it had been surveyed and entered on the grid, it could be picked out from every other square mile of territory, and be bought from an office three hundred miles away on the coast." Further, the RS should have increased land values by reducing uncertainty and conflict over titles The empirical analysis in this section uses both township and county level data and together provide an broad analysis of how the market for land is effected by land demarcation systems.

Convergence to an Efficient Parcel Size via the Market.

To start we expect that parcels under a decentralized metes and bounds system to have larger variation in parcel size compared to rectangular survey where sizes were generally prescribed by the system and less constrained by terrain (Prediction 5A).[81] To test this prediction, we regress the standard deviation of parcel acreage in all Ohio townships (n = 1353) against the percent area within the VMD and control for the ruggedness of the terrain.

Table 6 - Standard Deviation of Parcel Size within a Township

Independent Variables	STANDARD DEVIATION OF ACREAGE		
	(1)	(2)	(3)
% AREA IN VMD	509.5***	424.0***	509.5***
	[17.36]	[12.38]	[17.36]
RUGGEDNESS	721.1***	721.1***	-1475***
	[103.8]	[103.8]	[255.9]
INTERACTION	-2196***	-2196***	-2196***
	[276.8]	[276.8]	[276.8]
Constant	77.75***	105.8***	587.2***
	[5.501]	[3.838]	[16.40]
Observations (townships)	1353	1353	1353
R-squared	0.476	0.476	0.476
F Statistic	408.3	408.3	408.3

Notes: Results are reported for a weighted regression model of standard deviation in parcel size within a township. The parameter estimates for the independent variables are reported with standard errors listed below in brackets (*** p<0.01, ** p<0.05, * p<0.1). In Model 2, the ruggedness variable is centered about its mean. In Model 3, the VMD variable was reduced by one so that 100% within the VMD corresponds to a zero value. Township observations were weighted by the number of parcels within the township. When calculating standard errors corrected for spatial dependence (not reported) significance levels of the independent variables did not change.

As shown in the table, the nature of the survey has a substantial effect on the variation in parcel size. The coefficient on the VMD variable shows a statistically positive effect on the standard

[81] If the RS promoted market sales, then transactions should have been more common to consolidate properties.

deviation of farm size. The results indicate the change from an MB township to an RS township reduces the standard deviation in farm size from 587 to 78 when the terrain is completely flat, about seven and a half times its size. In terrain with average ruggedness, the standard deviation in farm size is five times smaller in the RS.

The ruggedness variable shows a statistically significant positive effect on the standard deviation of farm size in RS townships. Evaluated at its mean, a one standard deviation increase in ruggedness leads to a 27% increase in the standard deviation of farm size for an RS township. However contrary to our initial hypothesis, the ruggedness variable shows a statistically significant negative relationship with standard deviation of farm size in the VMD.[82]

County-Level Analysis: Transactions in VMD and Adjacent Counties.

To statistically analyze the effects of MB on land values we use county-level data from Ohio state reports, individual farm information from the 1850 and 1860 manuscript federal agricultural censuses, and 1870 parcel-level and U.S. Census data for Warren County, Ohio, which is split by the VMD.[83] To further examine the effects of land demarcation systems on land markets we use Ohio

[82] We speculate that this relationship may be driven by the claiming of smaller and sporadic pieces of land in more rugged terrain under MB. As such, smaller average parcel size would lead to smaller standard deviations. When we rerun the models using the coefficient of variation (SD/Mean) in parcel size as the dependent variable, this negative effect disappears.

[83] Brown, Clarence J. *Annual Report of the Secretary of State to the Governor and General Assembly of the State of Ohio for the Year Ending June 30, 1928*, Springfield, Ohio: The Kelly-Springfield Publishing Company, State Printers, 1928; *Annual Report of the Commissioner of Statistics to the General Assembly of Ohio for the Year 1857*, Columbus, Ohio: Richard Nevins, State Printer, 1858*; Second Annual Report of the Commissioner of Statistics, to the General Assembly of Ohio*: For the Fiscal Year 1858. Columbus, Ohio: Richard Nevins, State Printer. 1859*; Third Annual Report for the Commission of Statistics for 1860,* Columbus, Ohio, Richard Nevins; *Proceedings of the Several State Boards of Equalization, Assembled Under the Laws of Ohio, Previous to, and Inclusive of, the Year 1853*. Columbus, Ohio: Franklin Printing Company. 1854; "County Level Reports for 1850." *Eleventh Annual Report of the Commissioner of Statistics for 1868*, Columbus, Ohio, L.D. Myers and Bro. State Printer; Annual Report of the Secretary of State for 1870, Columbus, Ohio, Columbus Printing company; *Annual Reports of the Secretary of State for1871, 1874-5, 1876, 1875-6,* Columbus, Ohio: Nevins and Myers; Geospatial & Statistical Data Center. http://fisher.lib.virginia.edu/collections/stats/histcensus/php/county.php. June 2006.

county data from 1860 of the number of mortgages and conveyances as our measures of land market activity and estimate the following empirical model.[84]

As can be seen from estimates in Table 7, controlling for other factors, there are significantly more mortgages per acre, land conveyances, land conveyances per acre, and per capita in RS counties relative to MB counties. When the dependent variables are evaluated at their means, the coefficient for the VMD variable indicates that counties within in the RS system have 21% more mortgages per acre, 38% more conveyances, 44% conveyances per acre and a 40% more conveyances per capita when compared to counties under MB.

Table 7 - Land Transactions in VMD and Adjacent Counties

Independent Variables	(1) mortgages	(2) mortgages per acre	(3) mortgages per 1,000 population	(4) conveyances	(5) conveyances per acre	(6) Conveyances per 1,000 population
% AREA IN VMD	-72.97	-0.480**	-2.161	-109.4**	-0.435***	-4.104***
	[68.97]	[0.225]	[2.725]	[45.29]	[0.125]	[1.286]
POPULATION	0.00389**	2.09e-05***	--	0.00275**	1.25e-05***	--
	[0.00161]	[5.06e-06]	--	[0.00106]	[2.80e-06]	--
NUMBER OF FARMS	0.265***	0.000353	0.00309	0.0817	9.02e-05	-5.74e-05
	[0.0815]	[0.000215]	[0.00290]	[0.0535]	[0.000119]	[0.00137]
TOTAL FARM ACREAGE	-0.000248	--	-2.54e-06	0.000107	--	1.15e-05
	[0.000756]	--	[2.68e-05]	[0.000497]	--	[1.26e-05]
FARM VALUE PER ACRE	8.089**	0.0315***	-0.184**	5.311**	0.0206***	-0.0121
	[3.182]	[0.0108]	[0.0853]	[2.090]	[0.00599]	[0.0402]
	-682.5	-5.433	-128.5***	-416.1	-2.358	-62.40***
RUGGEDNESS	[1002]	[3.472]	[34.25]	[657.9]	[1.923]	[16.16]
	-121.1	0.282	31.67***	-110.5	-0.0394	11.44***
CONSTANT	[142.4]	[0.456]	[5.416]	[93.54]	[0.253]	[2.555]
Observations	39	39	39	39	39	39
Adjusted R-squared	0.849	0.858	0.226	0.814	0.872	0.362
F Statistic	36.57	46.88	3.224	28.78	52.75	5.316

Notes: Results are reported from weighted regression models of county-level indicators of land transactions. The parameter estimates for the independent variables are reported with their standard errors listed below in brackets (*** p<0.01, ** p<0.05, * p<0.1). Observations were weighted by percent farmland in the county. Standard errors corrected for spatial dependence (not

[84] Tables A-2 and A-3 in the appendix provide summary statistics for these data.

reported) had little effect on the interpretation of most variables in the model. For the VMD variable in each model the corrected standard errors were consistently smaller than the OLS standard errors.

Township-level analysis of land values

To further analyze the effect of land demarcation systems on land values we examined the value of land in adjacent townships along the border of the VMD. By examining townships along the VMD border we can control for many economic, demographic, and landscape variables. Figure 11 shows the township pairs used in this test. Data limitations prevent us from using all adjacent township pairs at this time. The results of the pair-wise comparison of mean township land values are reported in Table 8 and indicate that – as predicted – the value of land outside the VMD, using the rectangular survey, has higher values than similar land governed by metes and bounds demarcation.

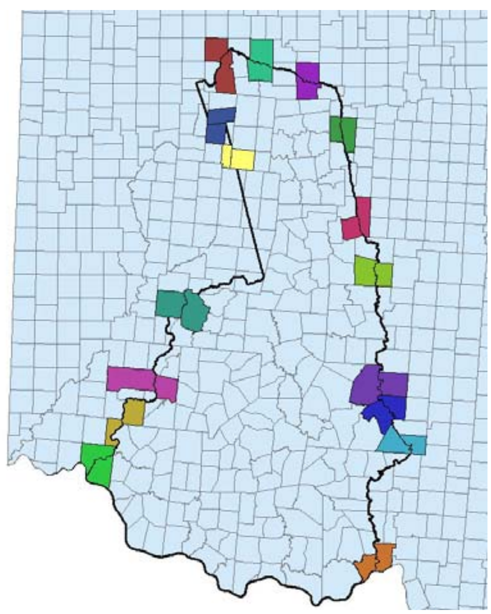

Figure 9. Paired Townships along the border of the Virginia Military District

Table 8 - Pair-wise comparison of mean Township Land Values

	Non-VMD	***VMD***
Mean	$40.24	$35.35
Variance	$302.87	$215.23
Observations	27	27
Pearson Correlation	0.62	
Hypothesized Mean Difference	0	
Df	26	
T Stat	1.80	
P(T<=t) one-tail	0.04	
t Critical one-tail	1.71	

Farm level estimates in Warren County, Ohio

To further test the prediction about land values we assemble data from Warren County where both metes and bounds and rectangular demarcation occurs in a small relatively homogeneous area. Using data from over 400 farms in this county we estimate various measures of land value in a model in which we include variables measuring the demarcation system, market variables, topography, and other controls. These estimates are show in Table 9.

The estimates in Table 9 show that an farm governed by metes and bounds has a consistently lower and statistically significant value compared to land governed by rectangular demarcation. In particular, using the mean values in model 1, total farm value per acre 38 percent higher in the rectangular survey ($106 per acre) compared to metes and bounds parcels in the VMD ($77 per acre). In addition, estimates of the effects of ruggedness and other factors conform to earlier estimates using other data.

Table 9 – Farm level value estimates, Warren County, Ohio.

	Total Farm Value per Acre		Real Estate Value per Acre	
VARIABLES	1	2	3	4
VMD	-29.14***	-34.23***	-67.15***	-69.06***
	[8.010]	[8.043]	[23.07]	[22.82]
Distance to Road	-13.69	-15.71	-1.902	-2.778
	[41.50]	[42.13]	[119.4]	[119.4]
Distance to Railroad	-2.640	-1.899	-0.0693	0.0704
	[2.201]	[2.260]	[6.318]	[6.398]
Distance to Water	-1.283	-1.225	-3.136	-3.122
	[0.936]	[0.951]	[2.691]	[2.694]
Distance to Market	-0.176	-0.176	4.574	4.668
	[1.293]	[1.332]	[3.680]	[3.731]
Occupation_2	8.118	11.23	100.7	103.4
	[23.70]	[24.27]	[66.44]	[67.07]
Occupation_3	84.44***	86.47***	40.57	40.75
	[25.84]	[26.23]	[80.83]	[80.88]
Occupation_4	5.180	16.10	34.14	39.31
	[23.89]	[24.10]	[67.08]	[66.66]
Age	-0.171	-0.118	0.948	0.974
	[0.210]	[0.214]	[0.614]	[0.615]
Gender	3.299	-0.541	-28.27	-30.20
	[25.84]	[26.23]	[72.45]	[72.45]
Ruggedness	-463.4**	-6.665	1641***	1898***
	[220.1]	[233.3]	[628.5]	[655.5]
Percent Prime Soil (always)	85.50***		42.91	
	[18.58]		[52.83]	
Percent Prime Soil (when drained)		65.34***		40.78
		[23.88]		[66.60]
Constant	93.48***	78.07**	-4.286	-18.74
	[23.46]	[30.57]	[67.92]	[86.15]
Observations	451	451	431	431
Adjusted R-squared	0.163	0.137	0.045	0.044
F Statistic	8.292	6.957	2.675	2.649

State-wide land value estimates at the township level

In Table 10 we report estimates of land value per acre across Ohio townships where we have collected farm value data from the 1850 and 1860 censuses. All values are in constant $1860, but we add a dummy variable for 1860 to reflect for overall growth in land values between the census years. We report estimates for land value as a function of terrain ruggedness, transportation access, year, and location within the VMD.[85] Because, as we show below, road density is correlated with the percent VMD, we report the land value regressions with and without road density. Land value is township average of farm value per acre from matched farms dataset from the 1850 and 1860 census manuscripts. Road density is length of roads in a township divided by the square root of the land area.[86]

Table 10 - Land Value per Acre, MB and RS

Independent Variables	(1)	(2)	(3)	(4)	(5)
% AREA IN VMD	-13.13***	-14.23***	-18.18***	-19.99***	
	[3.240]	[3.143]	[3.068]	[2.921]	
1860	18.68***	18.51***	18.50***	18.24***	18.56***
	[2.223]	[2.221]	[2.249]	[2.249]	[2.245]
ROAD DENSITY	0.677		0.938*		1.167**
	[0.492]		[0.494]		[0.482]
RAILROAD ACCESS	-1.028***	-1.067***			-1.362***
	[0.233]	[0.232]			[0.220]
RIVER DISTANCE	-0.217*	-0.241**	-0.0888	-0.116	-0.405***
	[0.114]	[0.113]	[0.112]	[0.111]	[0.105]
MARKET DISTANCE	-1.294***	-1.306***	-1.612***	-1.645***	-1.208***
	[0.319]	[0.319]	[0.315]	[0.315]	[0.322]
CINCINNATI DISTANCE	-0.424***	-0.447***	-0.421***	-0.453***	-0.348***
	[0.0378]	[0.0341]	[0.0382]	[0.0345]	[0.0331]
RUGGEDNESS	0.991	-6.347	-43.81	-56.48	19.74
	[37.13]	[36.77]	[36.14]	[35.58]	[37.21]
Constant	85.55***	93.47***	81.76***	92.69***	74.94***
	[7.244]	[4.408]	[7.279]	[4.463]	[6.822]
Observations (townships)	774	774	774	774	774
Adjusted R-squared	0.31	0.309	0.294	0.291	0.296
F Statistic	44.46	50.48	46.91	53.94	47.51

Notes: Results are reported from weighted regression models of average land value per acre at the township level. Land Values are in $1860. The parameter estimates for the independent variables are reported with their standard errors listed below in brackets (*** p<0.01, ** p<0.05, * p<0.1). Observations were weighted by percent farmland in the corresponding county. Correcting for spatial dependence in the residuals made some moderate changes to significance levels of some variables. The coefficient for Market Distance dropped from the 1% significance range to the 10% range in Models 1, 2, and 5 and from the 1% range to the 5% range in Models 3 and 4. Road Density dropped from the 1% significance range to the 5% range in Model 5. The spatial dependence correction also increased the standard errors of the VMD coefficient, but it remained statistically significant at the 1% level in all four models in which the variable appears.

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[85] Soil quality, which would impact land value, is highly correlated with topography (.70).

[86] 1860 Dummy – A value of one indicates that the farm value data came from the 1860 Agricultural Census. A value of zero indicates that the farm value data came from the 1850 Agricultural Census

The expected change in land value from location within the VMD is substantially negative and highly significant in the four models in which the variable appears. In the models where road density and/or railroad access variables are removed for potential endogeneity, the effect and significance of the VMD variable becomes more pronounced. Evaluating the results from Model 1, where the estimate for the VMD coefficient is the most conservative, we find that shifting from MB to an RS system yields an increase in land value per acre of 40.2% ($32.69 to $45.82) when assessed at the means of the independent variables.

G. Public Infrastructure: Roads and Railroads.

Prediction 6 states that investment in public infrastructure such as roads will be more extensive under a rectangular system where roads could run along defined, uniform property boundaries than under metes and bounds, where boundaries were irregular and vague. Indeed, scholars of land demarcation have noted this possibility. In his detailed study of the RS and MB in parts of four counties in northwestern Ohio in 1955 Thrower (1966, 86, 88-97, 123) stated that: "perhaps the most obvious difference between the systematic and the unsystematic surveys is the nature of the road network developed under these contrasting types of land subdivision" with greater road density in the RS areas.

To more precisely test for the effect of land demarcation systems on infrastructure investment, we estimated a measure of road density (the total length of roads in a township divided by the land area of the township). The specifications reported in Table 11 use variables that measure the fraction of a township governed by metes and bounds (in the VMD) and various other market and control variables.

Table 11 – Estimates of Road Density

Dependent variable: lLength of roads in a township divided by the square root of the land area.

Independent Variables	(1)	(2)	(3)	(4)
VMD_Percent	-1.595***		-2.044***	
	[0.311]		[0.285]	
Distance to river	0.00864	-0.0570***	-0.0280***	-0.0576***
	[0.0150]	[0.00991]	[0.0104]	[0.0101]
River Proximity	0.540***			
	[0.160]			
Market Distance	-0.0358	0.0182	-0.0350	-0.0418
	[0.0306]	[0.0353]	[0.0309]	[0.0327]
Cincinnati Distance	-0.0301***	-0.0231***	-0.0356***	-0.0233***
	[0.00390]	[0.00328]	[0.00359]	[0.00334]
Ruggedness	-19.15***	-14.58***	-18.59***	-18.99***
	[3.175]	[3.505]	[3.209]	[3.391]
Railroad Access		9.145***		
		[2.255]		
Constant	9.968***	9.242***	11.85***	10.66***
	[0.707]	[0.549]	[0.440]	[0.431]
Observations	437	437	437	437
Adjusted R-squared	0.327	0.256	0.310	0.230
F Statistic	36.24	31.04	40.24	33.49

As indicated in the table, there is a 20% increase in roads in RS. Roads, which were funded locally appear to have been sensitive to property boundaries. Railroads, which were more capital intensive may have been less affected by the property survey system. We test for the impact of the survey system on rail road density by estimated railroad density in a similar manner as the road density. These estimates are reported in Table 12.

Table 12 – Estimates of Rail Road Density

	(1)	(2)	(3)	(4)
Independent Variables	rrdensity	Rrdensity	rrdensity	rrdensity
VMD_Percent	-0.0422		-0.062	
	[0.0411]		[0.0406]	
rd_density	0.0130***	0.0138***		
	[0.00458]	[0.00452]		
Dist to river	0.000327	0.000148	0.000375	0.00011
	[0.00100]	[0.000986]	[0.00100]	[0.000989]
Market distance	-0.00000332***	-0.00000334***	-0.00000342***	-0.00000346***
	[0.000000598]	[0.000000598]	[0.000000599]	[0.000000599]
Dist to Cincinnati	0.000135	0.00026	0.000101	0.000286
	[0.000231]	[0.000197]	[0.000231]	[0.000197]
Ruggedness	-1.490***	-1.477***	-1.660***	-1.657***
	[0.325]	[0.324]	[0.320]	[0.320]
Constant	0.400***	0.374***	0.512***	0.484***
	[0.0621]	[0.0568]	[0.0479]	[0.0441]
Observations	1353	1353	1353	1353
Adjusted R-squared	0.052	0.052	0.047	0.046
F Statistic	13.29	15.73	14.27	17.23

Overall there is less effect on railroads as indicated by the low R squares. The VMD variable has a negative sign but is not significant.

V. CONCLUDING REMARKS.

This is the first economic study of the two dominant types of land demarcation systems – metes and bounds and the rectangular survey. We have developed a model of land demarcation to examine the use and effects of these two systems and tested a variety of hypothesis against data from Ohio where the two systems coexist as a result of exogenous political and economics forces. We have the following findings. First, we find that the characteristics of parcels in the metes bounds regimes of the Virginia Military District are strongly correlated with the topography of the land which is predicted by our model. We also find that in relatively flat topography where metes and bounds yields rectangular parcels these parcels are not uniformly aligned as they would be in the rectangular survey. Second, we find that in the Virginia Military District there was less land market activity, generally lower land values, fewer roads, and more property disputes.

With regard to the Virginia Military District, there is evidence suggesting the broader impact on the economy. Table 13 and Figure 12 show the pattern of population growth in the VMD relative to the rest of Ohio. The VMD was settled early and rapidly in Ohio. The first capital of Ohio was Chillicothe (in Ross County) and lay in the VMD just on the west bank of the Scioto River. In general, however, the VMD has lost ground as Ohio grew.

Table 13 - Comparison of Virginia Military District with the rest of Ohio*

	Population					
Year	VMD			Non-VMD		
	Total	Mean	% of State	Total	Mean	% of State
1810	53,744	5,374	13.88	177,016	6,808	76.71
1830	197,398	10,967	12.31	740,505	13,464	78.95
1850	274,867	18,324	9.72	1,705,462	23,687	86.12
1880	393,748	26,250	7.15	2,804,314	38,415	87.69
1900	404,035	26,936	6.02	3,753,510	51,418	90.28
1920	411,748	27,450	7.15	5,347,646	73,255	92.85
1950	478,487	31,899	6.02	7,468,140	102,303	93.98
1980	748,711	49,914	6.93	10,051,939	137,698	93.07
2000	970,658	64,711	8.54	10,393,743	142,380	91.46

* The VMD group that contains counties which have more than 50% of land in the VMD.

Moreover, the VMD has lower levels of urbanization than the rest of the state, with no major cities, even though the terrain and land quality do not vary importantly between the VMD and other nearby Ohio counties. Notably the cities of Cincinnati and Columbus lie just outside the VMD and grew on land governed by the rectangular survey.[87]

[87] Columbus actually lies in both the VMD and outside it (in Franklin County), but the overwhelming portion of the city is on the east side of the Scioto River where the rectangular survey governs.

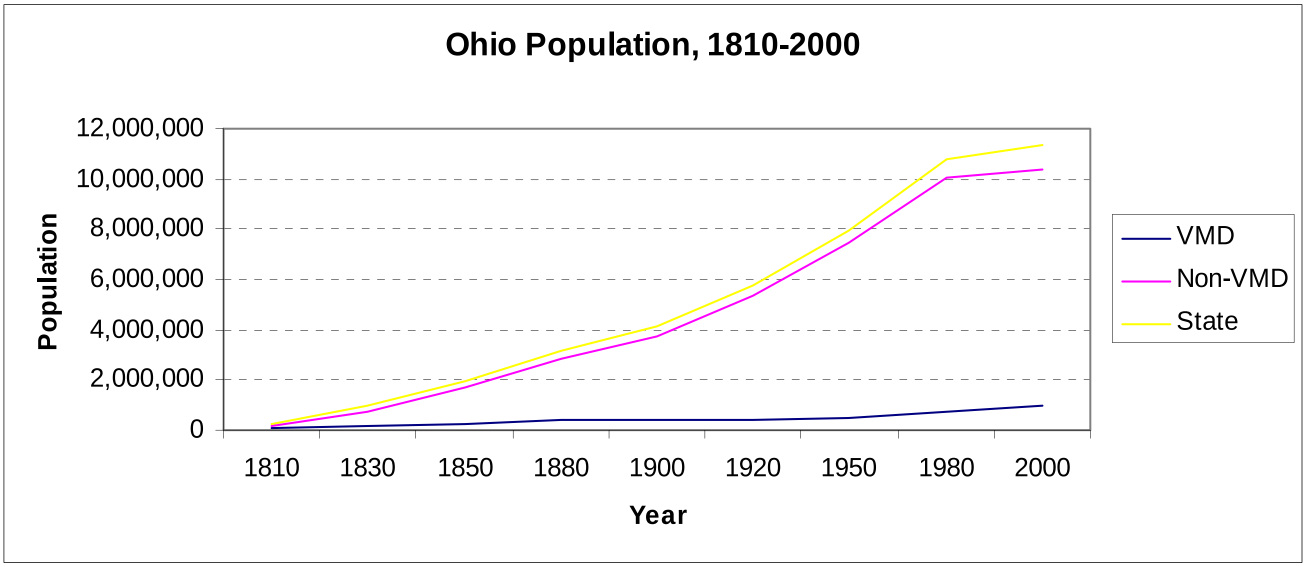

Figure 12. Ohio Population Over Time – VMD and Statewide

Our findings are suggestive of the importance of land demarcation in influencing the use of land and perhaps ultimately in economic growth more generally. Linklater (2002, 238-41), for example, comments on the subtle importance of uniform, systematic land survey in describing Stephen Austin's decision to adopt the RS in those parts of Texas not governed by Spanish and Mexican land grants. Seeing confusion over land boundaries in Kentucky and Tennessee where many of Austin's followers had originated, he selected the RS: "The advantages inherent in the square-based federal land survey gave the state's economy a vigor its neighbours lacked." Indeed, as suggestive of the effects of the survey on land markets, in those parts of the U.S. where rectangular survey dominated, the capital gains from land sale were the largest source of wealth creation (Ferrie1994, Galenson and Pope 1989).

We note that even though we find evidence that the rectangular system has some clear benefits over metes and bounds, we have no estimate of the costs of the RS system to indicate what the net effect might be. Furthermore, it is not clear how much we can extend our findings from the United States to less developed countries where metes and bounds dominate. And even within the

United States, our focus on Ohio, with its relatively mild and flat terrain, may cause us to overlook issues that arise in the Rocky Mountains or the desert southwest.

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Table A1: Ohio Counties by Land Survey Regime

Metes and Bounds	Mixed	Rectangular Survey		
Adams	Champaign	Allen (VMD)	Coshocton	Muskingum
Brown	Clark	Auglaize (VMD)	Cuyahoga	Noble
Clermont	Delaware	Butler (VMD)	Darke	Ottawa
Clinton	Franklin	Crawford (VMD)	Defiance	Paulding
Fayette	Greene	Fairfield (VMD)	Erie	Perry
Highland	Hardin	Hancock (VMD)	Fulton	Portage
Madison	Hamilton	Hocking (VMD)	Gallia	Preble
Union	Logan	Jackson (VMD)	Geauga	Putnam
	Marion	Knox (VMD)	Guernsey	Richland
	Pickaway	Lawrence (VMD)	Harrison	Sandusky
	Pike	Licking (VMD)	Henry	Sceneca
	Ross	Miami (VMD)	Holmes	Stark
	Scioto	Montgomery (VMD)	Huron	Summit
	Warren	Morrow (VMD)	Jefferson	Trumbull
		Shelby (VMD)	Lake	Tuscarawas
		Vinton (VMD)	Lorain	Van Wert
		Wyandotte (VMD)	Lucas	Washington
		Ashland	Mahoning	Wayne
		Ashtabula	Medina	Williams
		Athens	Meigs	Wood
		Belmont	Mercer	
		Carroll	Monroe	
		Columbiana	Morgan	

VMD indicates those rectangular survey counties included in the VMD region.

Table A-2
1860 County Data -- Variable Definitions and Summary Statistics

Variable Name	Definition	Mean	Standard Deviation	Minimum	Maximum
Dependent Variables					
NUMBER OF MORTGAGES	Number of farm mortgages recorded in the county	638.68	333.67	0.00	2,280.00
NUMBER OF MORTGAGES PER 100,000 ACRES		2.19	1.21	0.00	8.75
NUMBER OF MORTGAGES PER 1,000 PEOPLE		25.77	8.58	0.00	52.74
NUMBER OF CONVEYANCES	Number of conveyances of property recorded in county	278.07	248.99	0.00	1,892.50
NUMBER OF CONVEYANCES PER 100,000 ACRES		0.95	0.88	0.00	6.45
NUMBER OF CONVEYANCES PER 1,000 PEOPLE		10.30	3.98	0.00	24.25
CRIMES AGAINST PROPERTY	Number of crimes against property cited in each county (includes a variety of offenses, such as trespassing, illegal acquisition of property)	9.80	16.80	0.00	133.67
CRIMES PER 100,000 ACRES		3.51	6.49	0.00	51.27
CRIMES PER 1,000 PEOPLE		0.32	0.28	0.00	1.51
LAND DISTRIBUTION	The largest acreage held by a single owner divided by the average acreage held by an owner	36.63	43.52	0.00	304.35
Demographic Variables					
POPULATION	County population divided by 1,000	26.59	23.00	4.95	216.41
POPULATION CHANGE	Percent change in population from the previous decade (1850-1860)	26.96	37.88	-22.62	180.01
Economic and Land use Variables					
FARMS	Total number of farms in the county	1,970.22	644.04	404.00	3,520.00
TOTAL FARM ACREAGE	Total land in farms, including both unimproved and improved farmland				
FARM VALUE PER ACRE	Total value of farms divided by total farmland in county	31.74	12.82	12.67	98.47
EQUIPMENT VALUE	Total value of farm implements and machinery	198,168.55	92,216.46	17,005.00	427,963.00

LIVESTOCK VALUE	Total value of all livestock (horses, cattle, sheep, goats, oxen)	913,463.85	371,421.79	100,447.00	1,820,577.00
ORCHARD VALUE	Total value of all orchard products	21,923.97	15,136.24	948.00	68,184.00
GARDEN VALUE	Total value of all market garden products	10,312.65	49,388.88	25.00	459,196.00
SLAUGHTER VALUE	Total value of all slaughter animals	167,340.28	162,990.18	23,974.00	1,523,568.00
Land Regime Variable					
PERCENT RECTANGULAR SURVEY	The percent of land in the county in which the rectangular survey system is used*	0.837657	0.3221347	0	1
Control Variable					
TOPOGRAPHY	Scale of land topography (1-21, 1=flat plains, 21=high mountains)	8.02	7.01	1.00	19.00

Table A-3
1870 County Variable Definitions and Summary Statistics

Variable Name	Definition	Mean	Standard Deviation	Minimum	Maximum
Dependent Variables					
NUMBER OF ROADS	Number of turnpike and plank roads per county	11.90	13.80	1.00	58.00
NUMBER OF ROADS PER 100,000 ACRES		4.09	5.11	0.22	22.68
NUMBER OF ROADS PER 1,000 PEOPLE		0.42	0.50	0.03	2.17
LENGTH OF ROADS	Length (miles) of turnpike and plank roads per county	97.46	85.16	3.00	325.00
LENGTH OF ROADS PER 100,000 ACRES		33.07	30.28	1.16	127.07
LENGTH OF ROADS PER 1,000 ACRES		3.47	3.29	0.16	12.81
CRIMES AGAINST PROPERTY	Number of crimes against property cited in each county (includes a variety of offenses, such as trespassing, illegal acquisition of property)	22.30	23.88	1.00	178.50
CRIMES PER 100,000 ACRES		7.79	9.17	0.40	68.47
CRIMES PER 1,000 PEOPLE		0.71	0.35	0.06	1.95
Demographic Variables					
POPULATION	County population divided by 1,000	30.29	29.05	8.54	260.37
POPULATION CHANGE	Percent change in population from the previous decade (1860-1870)	14.01	19.73	-11.71	90.48
PERCENT ILLITERATE	Percent of the population over age 10 that cannot read	3.60	2.24	0.32	12.49
Economic and Land use Variables					
FARMS	Total number of farms in the county	Later			
TOTAL FARM ACREAGE	Total land in farms, including both unimproved and improved farmland				
FARM VALUE PER ACRE	Total value of farms divided by total farmland in county				
EQUIPMENT VALUE	Total value of farm implements and machinery				
ORCHARD VALUE	Total value of all orchard products				
GARDEN VALUE	Total value of all market garden products				

SLAUGHTER VALUE	Total value of all slaughter animals	
Land Regime Variable		
PERCENT RECTANGULAR SURVEY	The percent of land in the county in which the rectangular survey system is used*	
Control Variables		
TOTAL ACRES	Total acres of land in county	
TOPOGRAPHY	Scale of land topography (1-21, 1=flat plains, 21=high mountains)	
MANUFACTURING SITES PER ACRE	Number of manufacturing establishments in the county per 1,000 county acres	Later

Description of Legal Issues in Ohio Court Analysis

Survey Validity Issues:

These cases involve a dispute where two different surveys claim the same land. *E.g., McArthur v. Phoebus*, 2 Ohio 415 (1826). In these, the general question is which survey was valid and which was invalid. This should be differentiated from cases where two parties claim the same land because the survey, or several competing surveys, does not clearly delineate a line between the properties. These cases generally hinge on whether the survey was correctly recorded or implemented. In general, these cases are more common in VMD areas, but do exist in RS areas of Ohio, but the issues are far easier to resolve in the latter, generally hinging on resolving a clear surveying error, rather than conflicting land claims. *See Hamil v. Carr*, 21 O.S. 258 (Ohio 1871).

Boundary Issues:

This is a broader area of conflict, and basically encompasses when there is a dispute about where a boundary line actually stands. The majority of relevant cases fall in this area. These generally occur because the survey, or multiple surveys, do not make it legally clear where the boundary line stands. These cases also frequently occur when a deed does not make clear part of a plat it is granting.

Both these disputes occur in VMD and non-VMD areas, although the former are generally far more complex, hinge on far less clear legal principles, and as we show below occur with greater frequency than in RS areas.

Adverse Possession:

Ohio follows standard hornbook law on adverse possession, with the time being defined by statute, 21 years, and case law defining the elements. The generally required five elements of actual, continuous, open and notorious, hostile and exclusive possession exist. The Ohio Supreme Court, in *Yetzer v. Thoman*, 17 O.S. 130 (Ohio 1866), adopted the Connecticut Doctrine in regards to adverse possession. This doctrine essentially states that one can adversely possess land regardless of whether one knew that one did not actually have good title. Previous to this, courts presumably selectively required either the Maine Doctrine (requiring knowledge that you did not in fact have good title) or Good Faith (a requirement of a belief that you had good title to the land you were in fact adversely possessing), or did not inquire at all. The adoption of the Connecticut Doctrine allows for cases where two parties incorrectly believed they owned the same land. Ohio uses the related claim of "Acquiescence." If two parties knowingly agree to a different boundary line, when the correct boundary line is known by the parties, for the statutory period (21 years), then the party who loses land under the change cannot return the boundary to its correct position after this period through legal action. *See Bobo v. Richmond*, 25 O.S. 115 (Ohio 1874).[88]

Validity of Deeds/Patents:

These cases occur frequently and all hinge on whether a deed or patent was valid. While these are actually two fairly different legal issues, they generally depend on the same type of questions, namely was the deed/patent correctly recorded under the relevant statute and does the deed/patent correctly describe the land it grants. If not, the deed/patent is generally invalid. For the most part, these cases do not involve any boundary disputes, except in the cases where the validity of a patent is used as a collateral attack on cases of overlapping surveys. It is worth noting, however, that patent validity seems to be an issue mostly in VMD cases, largely due to the complexity of the statutes involved in the land grants.

The case, Ohio (Pt 1) 206 *Porter v Robb* from Clermont County illustrates some of the boundary problems found in the VMD. It is a case where a party mistakenly surveyed his entry and patented it, leading to conflict over the original survey. Notice the description of the land boundary: warrant No 77 used to claim land, "beginning two hundred poles on a right line, below the mouth of a creek, emptying into the Ohio, by computation ten miles above the mouth of the Little Miami, and nearly opposite a creek of equal size, running in on the oppose side, running thence up the meanders of the Ohio four hundred poles on a direct line; thence including the mouth of the creek…" The case shows how entries were filed with respect to earlier, adjacent ones, so if they were off, then all would be off. Many patents then are made at risk. The case also describes the process of using a warrant to make an entry, then surveying, and then patenting.

The problem of a chain of entries and surveys also appears in *Huston v McArthur*, 7 O (Pt 2) 54. An adjustment factor was included with each entry, and this caused conflict as the amount of the land claimed by various parties overlapped. The court claimed that to through out the adjustment factor in the VMD "…at this late period …would be fraught with much evil. It is insisted that it has ever been the custom in making surveys, to extend the lines five percent beyond the length called for, and that this custom has been so long and so uniformly persevered…" Court goes on to say, however, "That the locators in the district have been in the constant habit of appropriating by entry and survey more lands than their warrants called for,…"

[88] It should be noted that both Adverse Possession and Acquiescence are a defense to ejectment and generally may not be brought as initial actions by a plaintiff who wishes to claim the land.

Description of Parcel Data

We obtained the geospatial dataset *Ohio Original Land Subdivisions* (McDonald et al, Ohio Division of Geological Survey, Columbus, OH, 2002) as a set of geographic information system (GIS) files from the Ohio Department of Natural Resources. These data include a map that represents the only known digital compilation of the original land subdivisions in Ohio, styled after Sherman's (1922) map of original land subdivisions. The digital dataset can be used with geographic information systems (GIS) software, which has critical information on the geometry of parcels in MB and RS systems throughout Ohio, and obtain information on the precise spatial relationships of parcels, townships, and counties to relevant control variables such as topography and proximity to transportation. We use ArcGIS 9, a GIS software package to calculate shape values for each parcel, including the *p/a* ratio, the number of sides, and the alignment angle. The dataset contains over 73,000 parcels. The perimeter area ratio (*p/a* from our model) is an important measure of parcel shape and will be key in our analysis. This ratio is typically measured by $(p/\sqrt{a})$ to ensure that the numerator and denominator are both measured in the same units (Longley et al. 2005). Values for area and perimeter are being collected for each parcel using ArcMap Version 9.2. To measure topography we downloaded digital elevation models (DEMs) from the 1 Arc Second National Elevation Dataset (NED) (*Data available from U.S. Geological Survey, EROS Data Center, Sioux Falls, SD*) that span the state of Ohio. These DEMs are raster grids in which each cell (approximately 30 meters^2) is assigned an elevation value. While topography can be evaluated qualitatively, a DEM allows for precise, systematic, and quantitative measures of topography. We will use the standard deviation of elevation to reflect the topography of an area. The Spatial Analyst in ArcMap will be used to calculate the standard deviation of elevation on the county, township, and parcel levels.