Spatial Institutions in Urban Economies: How City Grids Affect Density and Development

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Abstract

In recent years, a number of empirical studies have identified strong connections between institutions and geography in the provision of public goods and economic development. This paper investigates coordinating effects of rectangular grids in cities. In 1811, Manhattan adopted its iconic rectangular street grid, contrasting with the decentralized, haphazard development of Lower Manhattan. The spatial patterns of both systems are largely persistent today and I exploit the spatial discontinuity in land patterns to estimate the effects of the institutional change. Regression estimates provide evidence that grids significantly increase land values and land use density relative to more haphazard demarcation patterns. Despite long-run differences in outcomes, urban demarcation patterns are slow to change, placing heightened importance on initial institutional investments.

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1 Introduction

Institutions set the rules for economic behavior and the efficiency of resource use largely depends on how institutions coordinate complex systems of economic interactions (Coase, 1937, 1960; Williamson, 1975; Ostrom, 1990). In recent years, a number of empirical studies have identified broad interconnections between institutions and geography to highlight their joint importance in explaining economic outcomes.\(^1\) However, there is a central need to explore the specific relationships in which geography and institutions interact to shape economic activity.

This project investigates urban grids; uniform, rectangular street networks that are prevalent in urban economies around the world. This urban land institution sets spatial rules which coordinate decisions involving property subdivision, building construction, and land use. In the aggregate, these decisions can have dramatic effects on the infrastructure, density and flow of a city.\(^2\) Though the importance and pervasiveness of urban grids has attracted significant scholarly attention from a variety of disciplines over time (Hurd, 2001; Acemoglu, Johnson, and Robinson, 2001, 2002; Rodrik, Subramanian, and Trebbi, 2004; Nunn and Puga, 2009).

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\(^1\)Studies include Gallup, Sachs, and Mellinger (1999); McArthur and Sachs (2001); Acemoglu, Johnson, and Robinson (2001, 2002); Rodrik, Subramanian, and Trebbi (2004); Nunn and Puga (2009).

\(^2\)As Jane Jacobs, Ed Glaeser and others make clear, the dense, interconnected nature of cities is what fosters personal interaction, communication, and specialization to make them hubs of commerce, productivity, and innovation.
1905; Stanislawski, 1946; Kostof, 1991; Reps, 1992; Conzen, 2001), there has been little rigorous economic analysis of this geographic phenomenon and its influence on urban development.

This paper addresses this gap by comparing the economic effects of centralized rectangular grid demarcation with those of decentralized demarcation systems. Decentralized systems allow individual landowners to set boundaries from the bottom up to fully dictate the spatial patterns of an area. In these systems landowners have the flexibility to customize boundaries to geography, local knowledge, and individual preferences. Centralized grids restrict this flexibility and entail upfront costs of planning, survey, removal of preexisting, inconsistent systems, and delaying productive use of the land. The willingness to adopt rectangular grids despite these costs suggests significant long-term potential benefits of the centralized system.

This paper argues that the advantages of the grid stem from its unique coordination properties and the failure of the decentralized system to internalize effects arising from shared property boundaries and the provision of collective goods such as public rights-of-way. By setting the initial partition of land into uniform rectangular blocks, grids limit individual incentives to form incompatible subdivisions. Adherence to the grid reduces irregu-
lar property shapes, increases connectivity, and helps coordinate a network of standardized property measurement, definition, and addressing. Furthermore, grids encourage investment through their predictability of expansion and ease of making uniform subdivisions to replicate construction processes. These factors promote real estate development and lower transaction costs in land transfers, critical for the dynamic restructuring of urban land as economic conditions change. Lastly, the alignment along linear paths also allows for easier access and lower input requirements for public infrastructure such as water lines and sewerage.

I investigate these implications using a specific empirical example from the island of Manhattan in New York City where a centralized grid and a decentralized demarcation system are adjacent. In 1811, the Commissioners’ Plan (CP) established a uniform rectangular street grid that stretches most of Manhattan Island. The plan is a departure from the uncoordinated and mostly haphazard system of Lower Manhattan (LM), where demarcation decisions by individual landowners were once decried by New York City officials as ones that “served only their private advantage, without a just regard for the welfare of others, and to the almost total neglect of public convenience and general usefulness.”
Nearly two centuries later, the street patterns in both the CP and LM remain strikingly similar. In the empirical analysis, I compare economics outcomes at the lot-level across the CP and LM to document both the historical impact of the CP and whether this institutional difference has consequences for today’s urban economy. Specifically, I exploit the discrete boundary of the CP using a spatial regression discontinuity design to estimate a CP treatment effect for various historical and contemporary outcomes. The empirical design is chosen with explicit recognition that institutions are not chosen randomly and often factors determining institutional have direct associations with the outcome of interest. This endogenous relationship between institutions and economic outcomes makes measuring the causal effects of institutions particularly difficult. The discontinuity approach used in this study largely alleviates this endogeneity concern assuming demarcation is the sole factor to change discontinuously at the treatment boundary.

Using a sample of vacant lot sales from 1835 and 1845, I find location within the CP significantly increases per-area land values by roughly 20 percent relative to LM. Similar changes across the boundary are not found in other covariates tested and estimates are robust to the inclusion of additional controls and different functional forms. Analysis of contemporary tax assess-
ments shows a similar difference in land values across the two areas and a larger CP effect with respect to total real estate value. The significant increase in property values in the CP is associated with greater uniformity in lot dimensions and use, lower vacancy rates, and greater building density. The largest differences in outcomes occur on the west side of the CP boundary where LM demarcation patterns exhibit the least structure and the starkest contrast with the CP grid. These findings indicate an enduring importance of the Commissioners’ Plan for Manhattan’s development and signify the potentially large coordination benefits provided by centralized grid systems.

The remainder of this paper proceeds as follows: section 2 covers a brief overview of rectangular grids and provides background on Manhattan’s demarcation and the Commissioners’ Plan of 1811, section 3 provides an economic framework to structure the empirical analysis, section 4 discusses data and empirical methodology, section 5 discusses estimation results, and section 6 concludes.
2 Background

Rectangular Grids and Alternatives

A remarkable amount of urban land throughout the world is demarcated into systematic rectangular grids. In particular, as American cities grew in the 19th and 20th centuries, they did so predominantly through grids. Rectangular grids are centralized land demarcation systems defined by orthogonal streets and uniform rectangular blocks. By setting the initial grid structure, the centralized plan provides an anchor for property boundaries and a template for further subdivision. The primary alternative to grids, at least prior to the 20th century, is a fully decentralized, unsynchronized street and plot system. In this system, property boundaries are demarcated by individuals and streets are opened on a case-by-case basis. In the aggregate, decentralized systems tend to lead to haphazard street patterns and irregular land subdivisions.

Though the formation of older cities was often decentralized, such as ones originating in medieval Europe, rectangular grids are observed as early as 2600 BC in the Indus Valley Civilization and were used in cities in ancient China, Greece, and Rome (Stanislawski, 1946; Kostof, 1991). Often a critical
prerequisite to grid implementation was the establishment of control over
the land prior to major settlement (Libecap, Lueck, and OGrady, 2011).
Over time grids became more widely implemented, and there increase in
use parallels the development of land ownership and land markets. The
prominent use of urban grids in the western hemisphere is likely due to this
development occurring prior to dense settlement in much of the region.

Rectangular grids are often observed in rural land as well, though not as
commonly as urban grid systems. One famous example is the Public Land
Survey System (PLSS) of the United States that covers the majority of the
country west of the original colonies. Starting with the Land Ordinance of
1785, the United States began selling off land in square “sections” of 640 acres
to raise revenue in order to pay off Revolutionary War debt. Congressional
debate surrounding the ordinance reveals that the rectangular system was
chosen for to its simplicity and clarity in defining property boundaries rela-
tive to the decentralized system of “metes-and-bounds” used in the original
colonies (Linklater, 2003; Libecap and Lueck, 2011).

Though grids are prevalent in the US, there is still considerable variation
in demarcation patterns across American cities. At one extreme are cities
lacking any identifiable demarcation structure, such as the city of Boston
(with the exception of the Back Bay neighborhood). There are also instances of centralized plans that are not uniform rectangular grids, such as the radial star patterns created by Pierre L’Enfant’s avenues in Washington DC or the concentric rings of Circleville, Ohio, but these types of plans are rare. Philadelphia, Cincinnati, and New Haven are among the earliest of US cities to initiate a grid in their city center. As these cities expanded, each added new sections periodically some irregular and some gridded, though additional grid sections tended to only be loosely coordinated with the original grid plan. Other cities, such as Brooklyn, appear as an uncoordinated patchwork of small private grids that expand into one another, with no one plan dominating. As the US population began to shift westward in the mid-to-late 19th century, large-scale uniform grids were much more common in cities from the outset. Chicago, Omaha, and Salt Lake City are classic examples.

To explore the economic impacts of different urban demarcation systems quantitatively, the empirical analysis uses a convenient example from Manhattan Island in New York City where a centralized grid system is adjacent

\footnote{Both cities had well documented difficulties selling and developing their uniquely shaped subdivisions. Linklater (2003) notes how triangular parcels created by the plan in Washington DC were avoided by investors and sat vacant for long periods. Circleville residents dissatisfied by awkward gaps and unproductive plot shapes eventually succeeded in replacing the circular plan with a rectangular grid in what Reps (1992) describes as “the first example of comprehensive urban redevelopment in the United States.”}
to a decentralized system. Manhattan is also of particular economic interest itself. New York City is the largest city in the United States and one of the foremost commercial centers in the world, and the origins of Manhattan’s grid system occur at a time of surging land values, population growth, and economic activity (Glaeser, 2005). Furthermore, Manhattan’s land is geographically constrained by its water boundaries, which places even greater importance on implementing efficient land systems. In the next two subsections, I describe the evolution of Manhattan’s early land systems and the later development of its city-wide grid.

### Early Manhattan Demarcation

Just four centuries ago Manhattan Island was inhabited by a scattered collection of Native American communities. The land was not formally subdivided, though commonly used transportation paths were apparent on the landscape (Burrows and Wallace, 1999; Homberger, 2005). More formal subdivision of the island began with Dutch colony of New Amsterdam in the early 17th century. Royal charters allocated several areas of land along the coast for business operations of the Dutch West India Company, and smaller land grants were increasingly given out to immigrant families as a way to stim-
licate population growth. Between the boundaries of the emerging property mosaic, several transportation routes developed, many of which would later become crystallized as public streets.

Throughout the period of Dutch control, Manhattan’s population centered around its southern port on the Hudson River. The port’s depth and accessibility made it a valuable trading post in the fur trade, and its proximity to the coast in multiple directions provided protection against outside attacks (Burrows and Wallace, 1999). As population grew, the fringe of the developing city expanded northward on the island. In 1664, the Dutch ceded control of the island to the British, and New Amsterdam was renamed the City of New York. Under the terms of the Dongan Charter of 1686, the city was declared owner of a large area of land in the center of the island that had not already been granted to individuals (Bridges, 1811).

The expansion of Manhattan’s population accelerated over the next century and the city occasionally sold off parts of its land to individuals as a way to generate revenue for municipal purposes without raising taxes. Following the revolutionary war the city was in considerable debt. The Common

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4 Descriptions of these property boundaries were often vague. For example, a description of an early holding on the north side of Beaver Street refers simply to a “lot on the ditch, bounded by a trench in the marsh” (Homberger, 2005).

5 The creation of streets prior to property boundaries, such as the establishment of lower Broadway, was the exception rather than the rule.
Council, the city’s governing body, ordered the survey and subdivision of its remaining land into a rectangular grid of 5 acre plots to be sold at auction. Despite the emergence of top-down demarcation structure in some rural parts of the island, the demarcation of property boundaries and streets in the core of the city continued to arise from the bottom up with no overarching structure. In a few cases, larger estates in Lower Manhattan were subdivided and sold off as land values rose. These subdivided estates tended to be more orderly, and many were demarcated into rectangular grids. However, demarcation was not synchronized with property outside of their initial claims (Kostof, 1991).

The Commissioners’ Plan of 1811

By the start of the 19th century the land pattern of Lower Manhattan was a haphazard array of crooked streets and idiosyncratic property boundaries (Rose-Redwood, 2002; Spann, 1988). The Common Council became increasingly concerned about the lack of connectivity and coordination among streets in the city as population grew. Soon after the start of the 19th century, the council became involved in street management by negotiating subsidies with private owners and developers for the promise of street creation and
reorganization. However these negotiations tended to evolve very slowly and were hard to enforce when an agreement had been reached. As a result, these actions did little to alter the status quo of the street system (Ballon, 2011, p. 17). The apparent difficulties of reorganizing established urban land patterns led the council to shift their focus to Manhattan’s urban frontier and the possibility of preemptive street demarcation. In 1807, the Common Council petitioned the state legislator for the authority to create a master street plan for the city. In its petition, the council states their ambition to provide for new streets “in such manner as to unite regularity and order with public convenience and benefit, and in particular to promote the health of the city.”

State authorization, they argued, would allow them to establish and enforce a consistent city-wide plan that would otherwise be susceptible to the private interests of the council and their predecessors (Bridges, 1811). The petition persuaded the state legislature to pass the Street Act of 1807. The act created a three-person state-appointed commission with “exclusive power to lay out streets, roads, and public squares, of such width, extent, and direction, as to them shall seem most conducive to public good.”

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6The council’s concern about health was tied to the belief that disease was transmitted by noxious and stagnant air, a commonly held view at the time. The city had also recently endured two separate epidemics of Yellow Fever, and the council reasoned that increasing connectivity between streets would improve air circulation and reduce the incidence of such epidemics.
state chose three prominent New Yorkers: Gouverneur Morris, Simeon De Witt and John Rutherford as the Street Commissioners of New York. The Commissioners were tasked with the design and implementation of a city-wide street plan that began beyond the “edge of dense settlement.” When the planned streets were opened, the city was to purchase the land required at “reasonable compensation.” The same compensation applied to existing structures in the path of new streets, but not to structures erected after the plan was filed. In general, payments were allowed to be offset by an assessment of the benefits accruing to the property owner from the new street.

Four years after the Street Act, the Commissioners along with their chief land surveyor John Randel, Jr. formalized a street plan for the city now known as the Commissioners’ Plan of 1811. The initial boundary of the plan started at the Hudson River and followed along Gansevoort Street, Greenwich Avenue, Art Street, and North Street (later renamed Houston Street) to the bank of the East River. From this boundary, the grid stretches up island to 155th street with little interruption.

The plan called for an orthogonal grid of streets and avenues that covers the vast majority of the unsettled parts of the island. In addition to the
Council’s motivation to simplify property boundaries and increase connectivity, the Street Commissioners saw their plan as an opportunity to promote real estate markets. In the remarks accompanying the Commissioners’ Plan, the Commissioners state that a key motivation for the rectangular design is that “straight-sided and right-angled houses are the most cheap to build and the most convenient to live in.” The choice of block dimensions also appears to be influenced by real estate considerations. Though blocks varied in length from 600-900 feet, their depth was uniformly 200 feet. This meant each block could accommodate rows of lots 100 feet deep with frontage on opposite streets. This depth was well-suited for the construction of row houses, the dominant structure in early American cities. Row houses are built on lots stacked side-by-side so that interior houses share walls with neighboring houses. Their depth was limited because light could only enter the house from the front and back. During this time period, row house depth almost never exceeded 100 feet.


3 Economic Framework

Costs and Benefits of Rectangular Grids

A key benefit of decentralized demarcation is that it allows individual landowners and developers the flexibility to customize boundaries to geography, local knowledge, and individual preferences. However, demarcation choices do not occur in isolation, and the inherent spatial relationships that exist between landowners, particularly in areas that are densely settled, can diminish the efficiency of the decentralized system. Externalities from shared property boundaries may require coordination between neighbors to jointly maximize the value of their land. For example, divergent interests arise when boundary location benefits one landowner at the expense of another. While owners are free to negotiate an agreement that is mutually beneficial, this coordination can be costly to achieve.

Larger coordination issues arise when demarcation choices affect utility across broader networks of landowners, such as with the alignment and connectivity of streets. Observation of decentralized demarcation in urban settings suggests these costs of coordination are substantial, as such systems are often criticized for their haphazard transportation routes, awkwardly shaped
lots, idiosyncratic property definitions, and costly addressing systems that require local knowledge to be useful (Kostof, 1991; Linklater, 2003).

These issues suggest that constraints on individual demarcation choices can improve welfare by increasing gains from coordination across land holdings.\(^7\) The basic mechanism of centralized systems is to establish a preemptive demarcation structure that is costly to deviate from and reorganize. If the costs of reorganizing demarcation outweigh the benefits of idiosyncratic customization, then the centralized system produces a different market outcome than one under a fully decentralized system.\(^8\)

While the shortcomings of decentralized systems help explain the role of centralized demarcation, the common choice of a rectangular grid structure requires more explanation. Several coordination benefits can be tied to the unique aggregation properties of rectangles. First, rectangles satisfy the geometric properties of a tessellation allowing them to be aggregated over a surface without gaps or overlaps (as opposed to circles, for example). Second, when rectangles are packed uniformly into grids, they exhibit linear and perpendicular alignment along boundaries, creating direct routes for

\(^7\)This is similar to Barzel (1997) notion of wealth-maximizing constraints on property rights.

\(^8\)Cases in which the reorganization of streets and property boundaries is legally prohibited can be interpreted as ones in which reorganization costs are very large.
transportation, lower input requirements for public infrastructure, and the basis for a Cartesian coordinate system useful for addressing and navigation.\textsuperscript{9} Lastly, the standardized dimensions of rectangular grids can reduce measurement costs in land markets, learning costs associated with specialized construction and land use, and uncertainty in development expansion.\textsuperscript{10}

Even in the absence of coordinated demarcation, there is a tendency toward rectangular lots in urban areas (Hurd, 1905; Ballon, 2011), which implies the rectangular unit also conveys private benefits at the lot-level. For one, rectangular boundaries are simple to define and require little specialized knowledge to understand. This simplicity can serve to reduce transaction costs for boundary enforcement and exchange (Libecap and Lueck, 2011). In urban areas, where land is in high demand, buildings dimensions are likely to be constrained by the dimensions of the underlying lot. The right angles of rectangles are thought to be conducive for building construction (Stanis-

\textsuperscript{9} The prevailing address system of urban grids in the Midwest and West relates all house numbers to a single point of origin, usually an intersection of two streets in the city center. Address numbers then increase as one moves orthogonally from a baseline street and resets at regular intervals at each new block with the leading number increasing by one (i.e. 100,101,102; 200,201.).

\textsuperscript{10} In this way, uniform demarcation is closely aligned with Merrill and Smith (2000) analysis of the \textit{numerus clausus} principle in which property rights are restricted to a limited number of standard forms to reduce measurement costs.
lawski, 1946) and convenient for use (Linklater, 2003; Steadman, 2006).

In the next section I add structure to the discussion above to help guide the empirical analysis.

**Analytical Model**

This section presents an analytical model to compare demarcation outcomes in a decentralized system and one in which a uniform grid is preemptively laid out by a central planner. The land system in question is made up of independent subdivisions, each owned by a separate developer. A subdivision can be thought of as a single lot or higher levels of aggregation such as a block. Each subdivision takes one of two demarcation types: a specialized subdivision ($S$) and a standard rectangular grid subdivision ($C$). Rectangular grid subdivisions are assumed to be compatible with each other.

**Setup**

Consider a set subdivisions indexed by the parameter $l \in [0,1]$. For each $l$ a developer chooses either specialized demarcation ($S$) or rectangular grid demarcation ($C$). The value of a specialized subdivision is specific to the
developer and denoted by $v^S(l) = l$. 11

Let $f$ be the fraction of rectangular grid subdivisions within a system. Larger values of $f$ indicate a more coordinated grid network which increases the value of all subdivisions that are compatible with this network. Specifically, the value of a rectangular grid subdivision is denoted as

$$v^C = k + \gamma f$$
where $k > 0$, $0 \leq \gamma < 1$.  \hspace{1cm} (1)

in which the parameter $k$ represents the private value of a rectangular subdivision in isolation (i.e. as if it had no economic relationship with other subdivisions) and $\gamma$ indicates the marginal gains from increasing coordination across subdivisions.

**Decentralized Demarcation**

The objective of each developer is to maximize the value of his subdivision. Therefore developer $l$ chooses $C$ whenever $v^C > v^S_l$. Because $l$ is an ordered index of developers from 0 to 1, the fraction of developers choosing $C$ in an interior equilibrium corresponds the marginal developer indifferent between $S$ and $\text{specialized subdivision}$ with an index between 0 and $l$ have a value less than $v^S(l)$. 

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and $C$. The interior equilibrium condition is $v^S(f^*) = v^C(f^*)$. Rearranging the equilibrium condition yields the value $f^* = \frac{k}{1-\gamma}$. This equilibrium is depicted in the first panel of Figure 1.\footnote{The particular equilibrium shown uses the parameters $k = 1/5$ and $\gamma = 1/2$}
Figure 1: The graphs depict land market equilibriums under different demarcation regimes. In each panel the vertical axis represents the value of a land subdivision and the horizontal axis represents a continuum of developers indexed by $l$. Developers choose a demarcation type to maximize the value of the subdivision. The variable $v^C$ represents the value of a compatible grid subdivision and $v^S$ is the value of a specialized subdivision. The fraction of compatible subdivisions $f$ is determined in equilibrium. The left panel shows the equilibrium for a decentralized system. The thick black line indicates the value of $l$’s subdivision in equilibrium for all $l$. The right panel compares the decentralized equilibrium to one in which a planner demarcates a centralized grid across subdivisions prior to land allocation. In the centralized system, a specialized subdivision requires an additional switching cost of $x$. The thick dashed line represents the centralized equilibrium. The area of the light green region equals the value gained by developers from centralization and the area of the dark red region equals the value lost.
Centralized Grid Demarcation

Now suppose a central planner preemptively demarcates a rectangular grid across all subdivisions. Developers subsequently choose between $C$ and $S$, but now incur an additional reorganization or switching cost $x > 0$ whenever $S$ is chosen. The interior equilibrium becomes

$$f(k, \gamma, x) = \frac{k + x}{1 - \gamma} \quad \text{where } x \in [0, 1] \quad (2)$$

of which $f^* = f(k, \gamma, 0)$ is equivalent to decentralized demarcation. Because $k + x > 0$, there exists a positive fraction of developers choosing $C$ in equilibrium for any permissible value of $\gamma$ and $x$. Interior solutions require $k + x + \gamma \leq 1$ to ensure both types of subdivisions are chosen in each equilibrium and that their proportions are influenced by $x$.\footnote{I ignore corner solutions because they are not relevant to the empirical setting. Small grid subdivisions are evident in decentralized Lower Manhattan, and even in the strict layout of the Commissioners’ Plan, there are still several instances of deviation from the original structure.} Plugging $f(k, \gamma, x)$ back into $v^C$ yields

$$v^C(k, \gamma, x) = \frac{k + \gamma x}{1 - \gamma}. \quad (3)$$

Inspection of Equations (2) and (3) shows $f()$ and $v^C()$ are increasing in $k$, $x$, and $\gamma$. The increase in $x$ has both a direct and indirect effect on $f$. The direct
effect comes from the downward shift in $v_S(l)$ that induces $x$ more developers to choose $C$. The indirect effect arises because network benefits are conveyed to compatible subdivisions when $f$ increases. This upward pressure on $v^C$ induces an additional $\frac{\gamma x}{1-\gamma}$ developers to choose $C$ in equilibrium.

**Effect on Total Land Value**

The total value of the land in equilibrium, is simply the sum of land values over all subdivisions:

$$V = f(k, \gamma, x)v^C(k, \gamma, x) + \int_{f(k, \gamma, x)}^{1} v_S^S(l, x)dl. \quad (4)$$

The first term in $V$ represents land value within rectangular grid subdivisions and the second term represents land value in specialized subdivisions. The right panel of Figure 1 compares centralized and decentralized equilibriums. The thick smooth line represents the value of a developer’s choice at each $l$ in the decentralized setting and the thick dashed line represents the value at each $l$ in the centralized setting. The change in $f$ is depicted on the horizontal axis. The total land value in each system is equal to the area under their respective equilibrium curves. The total value gained by developers under the centralized system is represented by the light green area in the figure and the
value lost is represented by the dark red area. The figure also shows that the distribution of costs and benefits are unequal across developers. Developers that always choose $C$ regardless of the system fair best under the centralized system, developers that always choose $S$ fair worst, and developers induced to choose $C$ in the centralized equilibrium are only better off when $l < v^C(x)$.

The difference in total land value across decentralized and centralized systems can be seen more generally by evaluating how $V$ changes as $x$ increases from 0. The derivative of $V$ with respect to $x$ is:

$$\frac{dV}{dx} = \frac{k + x}{(1 - \gamma)^2} - 1.$$ (5)

Two important relationships follow from Equation (5). First, the derivative is shown to be increasing in $x$ and is positive at $x = 0$ whenever $\gamma > 1 - \sqrt{k}$. This indicates that it is possible for a centralized grid plan to improve upon the decentralized outcome when the benefits of coordinating grid subdivisions are sufficiently strong and the intrinsic value of rectangular subdivisions is sufficiently high. Second, the parameter restrictions required to obtain an interior solution imply that the derivative is strictly negative.\footnote{The figure shows equilibriums for the parameters $k = 1/5$, $\gamma = 1/2$, and $x = 1/4$. This corresponds to about a 13 percent increase in total land value under the centralized system.}
when $\gamma = 0$.

This relationship suggests an empirical test for the presence of coordination benefits. In the absence of coordination effects, total land value must be lower in the centralized grid system. It follows that an increase in total land value attributable to the centralized system indicates the presence of coordination benefits.

The empirical analysis in the next section follows the general progression of the model above. I first demonstrate differences in lot-level demarcation patterns across the centralized CP and decentralized LM areas. I then compare property values across the two regions and provide evidence that the CP leads to higher land values and more intense building development, and that these differences are greatest when compared to the least coordinated areas of LM.

4 Empirical Framework

The location of Manhattan Island is shown in Figure 2.\textsuperscript{15} The island is flanked by the Hudson River on its west side separating it from New Jersey.

\textsuperscript{15}Manhattan Island makes up the majority of the New York City borough of Manhattan which also includes smaller nearby islands.
and flanked by the East River on its east side separating it from Long Island. The southern tip of Manhattan borders Upper New York Bay, a natural harbor of the Atlantic Ocean and important commercial waterway. Manhattan Island is oblong extending thirteen miles up the Hudson River and never more than three miles between rivers.

The Commissioners’ grid covers most of the island today. The right panel of Figure 2 indicates the southern boundary of the Commissioners’ Plan in green. The shaded region of the map covers land within 2 miles of the boundary, denoting the spatial extent of the main sample in the empirical analysis. I define the sample area above the boundary as CP and the area below as LM, the latter abbreviation referring to the area’s rough correspondence to colloquial definitions of Lower Manhattan. The red point on the map marks the location of City Hall, which I use as the historical midpoint of the central business district (CBD).

\footnote{The map is rotated so that the avenues of the Commissioners’ Plan run vertically on the page. Despite the convention of referring to Manhattan’s avenues as running north-south, their true orientation runs 29 degrees east of north.}

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Figure 2: The left panel of Figure 2 shows Manhattan Island outlined in yellow between the coast of New Jersey to the west and the New York City boroughs Brooklyn, Queens, and the Bronx are to the east. The map on the right shows an outline of Manhattan Island rotated 29 degrees counterclockwise so avenues within the Commissioners’ Plan (CP) run vertically up the page. The boundary of the Commissioners’ Plan (CP) is indicated in green. The CP occupies the area above the boundary and LM the area below. The shaded area corresponds to land within two miles of the CP boundary, the maximum extent of the samples used in the analysis. The red dot indicates the location of New York City Hall, used to denote the location of the historical central business district (CBD). Source: Esri, 1-cubed, USDA USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community.
The Identification Problem

The goal of the empirical analysis is to estimate the impact of the Commissioners’ Plan on urban economic outcomes by comparing land located within the CP, the treatment area, with nearby land in LM, the control area. In order to make consistent and credible estimates of the CP’s impact on economic outcomes, it is critical to rule out the influence omitted factors related to treatment assignment. In this case, treatment assignment is a function of location, a variable that is also fundamentally important in determining urban economic outcomes. Most notably, the monocentric city model developed by Alonso (1960, 1964), Muth (1969) and Mills (1967, 1972) shows that equilibrium land values should decline with increasing distance from the central business district (CBD) to offset higher commuting costs. In the case of New York City, the historical CBD is located in Lower Manhattan near City Hall (Atack and Margo, 1998). Without accounting for proximity to the CBD, an estimate of the CP effect on historical land values will be biased downward.\footnote{The monocentric city model is less applicable to the contemporary analysis due to the rapid development of a second business center in Midtown Manhattan during the 20th century.}

More generally, it is likely that demarcation choices are endogenous to the
characteristics of an urban area. One potential resolution to this problem is to use a regression control model. These models identify the treatment effect assuming all factors correlated with treatment assignment that also influence the outcome are “controlled” for in the right hand side of the regression equation. This assumption is very strong in most applications due to the difficulties of observing all relevant factors or even knowing which factors are relevant. I follow a regression discontinuity design, a related but distinct approach, which exploits the discrete geographic boundary of the Commissioners’ Plan. The key advantage of this design is that treatment assignment is fully determined by observed location.

Controlling for a flexible function of spatial coordinates absorbs variation that flows continuously over space such as distance to the CBD, and isolates the discrete change at the treatment boundary. This change identifies an average CP treatment effect as long as no omitted factor jumps discontinuously at the same spot. Though this issue remains, the scope of the identification problem is considerably reduced.

A general problem with discrete spatial changes in institutions or policies, however, is that treatment boundaries are often located at existing discontinuities (for example, a policy boundary defined by a river). In this study,
the location of the treatment boundary is determined by the interaction of two key factors. First, the high costs of reorganizing established land patterns in Lower Manhattan required the CP boundary to be located on the urban frontier. Second, the location of the frontier is determined by Manhattan’s population, which was expanding at unprecedented rates in the early 19th century (Glaeser, 2005). This suggests the location of the plan’s initial boundary is largely a function of continuous time rather than inherent changes in the characteristics of the land itself.\textsuperscript{18}

Another identification problem in this line of research is the bundling of institutions in treatment and control areas. This is particularly common when changes occur at administrative boundaries, such as state lines. In these cases, the treatment effect of interest cannot be separated from the total effect of the institutional bundle. This problem is less of concern for this study. While the CP boundary has historical significance, it is not the basis for subsequent boundaries to political jurisdictions, school districts, police precincts, or zoning.\textsuperscript{18}

\textsuperscript{18}In contrast, the grid plan was purposefully kept from extending past 155th street due to a abrupt change in the steepness of topography in present-day Washington Heights.
Empirical Specification

The empirical analysis uses data at the city-lot level. Let the vector \((x_i, y_i)\) denote the location of lot \(i\) and \(CP_i = \{0, 1\}\) indicate whether lot \(i\) is within the CP area. The basic estimating equation of the regression discontinuity design is

\[
Z_i = \alpha + \theta CP_i + W_i' \beta + f(x_i, y_i) + \epsilon_i
\]

where \(Z_i\) is the outcome of interest, \(W_i'\) is a vector of control variables, \(\epsilon_i\) is a random error term, and \(f(x_i, y_i)\) is a flexible polynomial of spatial coordinates and associated regression coefficients. In the empirical analysis, I use a cubic xy-polynomial as the main functional form.\(^{19}\) Unbiased estimates of \(\theta\) represent the average treatment effect of the CP relative to LM.

The spatial discontinuity approach has important differences from a standard regression discontinuity approach. In the standard design the treatment assignment rule depends on whether or not a scalar “forcing” variable crosses a threshold point (Lee and Lemieux, 2009). In the spatial design, the rule defining treatment is location-based and therefore depends on a two-dimensional vector of covariates \((x, y)\) and their relationship with a treatment boundary rather than a single point. The added complexity of an additional\(^{19}\)

\[
\text{Specifically } f(x_i, y_i) = \delta_1 x + \delta_2 y + \delta_3 x^2 + \delta_4 y^2 + \delta_5 xy + \delta_6 x^3 + \delta_7 y^3 + \delta_8 x^2 y + \delta_9 x y^2.
\]
forcing variable has led some to transform geographic designs into a single dimension using distance to the treatment boundary as a scalar forcing variable. However, this approach does not appropriately capture distance between observations, such that any two observations near the treatment boundary may still be arbitrarily far apart along the boundary. This simplification undermines a key feature of RD designs, namely that estimates are driven by comparisons across treatment and control in close proximity. In an urban economic environment where location is a fundamental determinant of economic outcomes, the use of a two-dimensional spatial control function allows comparisons to be more spatially precise.

Another difference of the two-dimensional design is that treatment effects are identified at every point along the treatment boundary (Imbens and Zajonc, 2011). Therefore the average treatment effect can be decomposed into region specific effects. I explore this heterogeneity in the empirical analysis along east and west regions of the CP boundary.

Two final estimation issues concern the appropriate weights for observations and autocorrelation of error terms. First, because the empirical analysis focuses on the CP’s impact on the total value of the land in question, regressions are weighted by lot area so that the average treatment effect corresponds
to per-area changes in the outcome. The second consideration is the presence of spatial dependence in the error terms across lots. The spatial nature of the outcomes and covariates used in the analysis may introduce this type of spatial dependence, especially if there are aspects of the spatial process that are measured incorrectly. In the empirical analysis, I estimate standard errors clustered by groups of nearby observations. For the contemporary tax lot sample, observations are clustered by city block. For the historical sample, observations are overlaid with a square lattice and clustered in 1,000x1,000ft cells.

**Samples**

The validity of the RD design can be assessed by rerunning the analysis with additional control variables and on a restricted set of observations closer to the boundary. Figure 3 shows two maps of the sample region. The left map shows the sample extents for 2-mile, 1-mile and 0.5-mile radii around the CP boundary. The narrower sub-samples provide a check on results in the 2-mile sample. If the treatment effect is identified in the 2-mile sample, the estimates should be relatively stable across the narrower samples. The left map also shows a buffer within 400 feet of the CP boundary. In this region,
blocks in the treatment and control groups are directly adjacent. Since the grid derives benefits from coordinating neighboring land areas, the directly adjacent blocks will not capture the full treatment effect. To avoid these edge effects I omit observations located within this buffer.
Figure 3: The above maps show the extent of the samples used in the analysis overlaid on an approximate 18th century street map modified from a historical map constructed by the Center for Population Economics at the University of Chicago. The boundary of the CP is indicated in green in both maps. The panel on the left shows the sample extents for 2-mile, 1-mile, and 0.5-mile radii around the CP boundary. The panel on the right shows west and east samples used in the analysis of contemporary tax lots. Observations within 400 feet of the CP boundary are omitted in all samples to avoid edge effects as described in the text. The omitted section between east and west samples is a vertical extension of Art Street, an original segment of the CP boundary that was later reorganized.
Though the majority of the CP boundary is intact today, a key segment has been altered. Art Street, the half-mile stretch in the center of the CP boundary, along with nearby streets in the LM region have since been reorganized into a rectangular grid to align with the Commissioners’ Plan. This subsequent integration of streets blurs the precise location of the treatment boundary and makes it unclear whether the reorganized streets should be considered part of treatment or control. To address this concern, the empirical analysis proceeds in two ways. The first approach uses data along the full extent of the boundary to evaluate the CP’s effect on historical and contemporary outcomes. This method maximizes the use of the small historical sample, which is unaffected by the street change, and allows more direct comparisons across time periods.

The second approach focuses explicitly on the larger contemporary tax lot sample. To avoid capturing the effects of the Art Street reorganization, I omit the region that extends along the vertical axis from Art Street’s historical location. The omitted area splits the sample into two distinct regions shown in the right panel of Figure 3. The division of the island into east and west regions is also a natural place to explore heterogeneity in the CP treatment effect. The west sample exhibits more irregularity and less uniformity
near the boundary in the LM region compared to the east sample. In fact, demarcation below the boundary in the east region conforms to a small, yet rather systematic rectangular street grid that was established through the subdivision of a colonial estate in the late 18th century (Kostof, 1991). If average differences in economic outcomes across the CP boundary are driven by the characteristics of the different demarcation regimes, then estimated differences should be magnified in the west sample where treatment and control are more different and muted in the east sample where treatment and control are more similar.

Data Construction

The empirical analysis explores both historical and contemporary outcomes. The historical data is drawn from the first half of the 19th century, which potentially reduces the presence of confounding factors. For instance, this earlier urban setting places the analysis in a time period when transportation considerations are considerably less consequential. Furthermore, the historical time period predates zoning laws and other land use regulations that can have direct effects on development outcomes.\(^{20}\) On the other hand,

\(^{20}\)New York’s first zoning regulation was adopted in 1916.
contemporary data is more readily available, provides larger sample sizes, a
greater range of outcome variables, and a setting that is more familiar to the
average reader. Comparison across time periods sheds light on the persist-
tence of demarcation institutions, and their evolving relationship with urban
outcomes.

Information on historical land values are drawn from unpublished data on
vacant land sales compiled by Jeremy Atack and Bob Margo from archives of
New York City daily newspapers.\textsuperscript{21} Each observation includes the location of
the lot sold, the lot dimensions, and the sales price. As stated in Atack and
Margo (1998), a typical entry reads (\textit{New York Herald}; January 10, 1845)

1 lot on the south side of Horatio street, 110 feet 9 inches

east of Hudson street, 25x87 1450

The above entry corresponds to a 2,175 square foot rectangular lot on Ho-
ratio street that sold for a price of $1,450. The location information in each
entry is geo-coded to a digital street map of Manhattan created by the Cen-
ter for Population Economics (CPE) at the University of Chicago.\textsuperscript{22} When

\textsuperscript{21}Atack and Margo (1998) use this source data to estimate Manhattan’s land-rent gra-
dient during the 19th century.
\textsuperscript{22}Carlos Villarreal greatly assisted this process by sharing his own geo-coding of the
data.
streets could not be identified on the CPE map I locate streets using descriptions from the web site www.oldstreets.com. Additional methods used to locate observations are detailed in the data appendix. Lots are distinguished as irregular if more than 2 dimensions are listed and are considered to be rectangular otherwise. I follow Atack and Margo in calculating an upper-bound area for irregular lots as the area of a circle with a circumference equal to the perimeter of the irregular lot.

One drawback of only using vacant land sales is the potential for selection bias. There is a concern that omitted factors cause lots to remain vacant in an otherwise built-up area. This type of bias should be reduced in samples in which vacant land is ubiquitous on both sides of the boundary. I limit the sample to data from 1835 and 1845, the two earliest time periods in which data is collected. The sample totals 345 observations with 14 percent of the observations drawn from Lower Manhattan. These are the only years in which there are substantial observations in the control area in Lower Manhattan. The next available year data is collected is 1860. By this time very little land near the CP boundary is left undeveloped and too few observations exist in the LM area to make meaningful comparisons across the CP boundary.
Contemporary data on land values, building values and lot characteristics are drawn from the MapPLUTO database, a comprehensive spatial data set of New York City tax lots maintained by the Department of City Planning (DCP), New York City. Unlike the historical data set, the MapPLUTO database covers every lot in Manhattan and therefore sample sizes are much larger. The MapPLUTO data set combines data created by the DCP and data sources from various agencies in New York City. Specifically, I use data on assessed valuations of land, buildings, and total real estate for each tax lot estimated by the New York City Department of Finance (DOF) for 2013 property taxes. According to DOF documentation, land values are calculated as if the lot were vacant. Assessments for the majority of lots is based on average market prices from a sample of similar properties that have been sold in the previous year. Total real estate values include a valuation of everything that is typically transferred when a property is sold including buildings, garages, etc.

I also construct data on average values for physical geography indicators within the region of each observation including measures of elevation, terrain slope, and historical wetland area. For the contemporary sample, I calculate values within the lot boundaries specified by the shapefile from the
MapPLUTO data set. For the historical sample I calculate values within a defined radius around each geocoded point, so that the corresponding circle equals the reported area of the lot. Additional information on variable construction can be found in Appendix 2.

5 Estimation Results

Geography Across the CP Boundary

This subsection explores the relationship between the CP treatment and how geographical variables evolve across the treatment boundary. The first set of results investigates indicators of physical geography which play a critical role in Manhattan’s development. Table 5 compares the physical geography across the historical and contemporary samples and across treatment and control. The reported means show that both historical and contemporary samples are comprised of relatively low-lying, flat land with slightly hillier land in the tax lot sample. The table also reveals the rather sizeable portions of the land that are not naturally solid and dry. More than 10 percent of both samples lie on areas that are or were once considered to be wetlands.

23Manhattan’s topography gets considerably more rugged north of the sample region near Harlem and Washington Heights neighborhoods.
Table 1: Physical Geography

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Vacant Land Sales (1835, 1845)</th>
<th>Tax Lots (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (1) CP Coefficient (2)</td>
<td>Mean (3) CP Coefficient (4)</td>
</tr>
<tr>
<td></td>
<td>(1) (2)</td>
<td>(3) (4)</td>
</tr>
<tr>
<td>Elevation (ft above sea level)</td>
<td>10.1 (-0.44)</td>
<td>39.5 (4.9)</td>
</tr>
<tr>
<td></td>
<td>(4.7) [0.39]</td>
<td>(29.9) [4.7]</td>
</tr>
<tr>
<td>Terrain slope (degrees)</td>
<td>0.56 (-0.47)</td>
<td>0.78 (0.25)</td>
</tr>
<tr>
<td></td>
<td>(0.41) [0.36]</td>
<td>(1.12) [0.17]</td>
</tr>
<tr>
<td>Historical wetlands (share)</td>
<td>0.14 (-0.07)</td>
<td>0.14 (0.10**)</td>
</tr>
<tr>
<td></td>
<td>(0.25) [0.05]</td>
<td>(0.34) [0.04]</td>
</tr>
<tr>
<td>Waterfront lot</td>
<td>0.01 (-0.02)</td>
<td>0.05 (0.03)</td>
</tr>
<tr>
<td></td>
<td>(0.08) [0.02]</td>
<td>(0.22) [0.04]</td>
</tr>
<tr>
<td>Observations</td>
<td>345 345</td>
<td>16,843 16,843</td>
</tr>
<tr>
<td>Observations (CP)</td>
<td>296 296</td>
<td>10,257 10,257</td>
</tr>
<tr>
<td>Observations (LM)</td>
<td>49 49</td>
<td>6,587 6,587</td>
</tr>
</tbody>
</table>

Note. The above table describes the physical geography of the historical sample of vacant lot sales from 1835 and 1845 and 2012 tax lot data from Manhattan. Columns 1 and 3 report mean values with standard deviations below in parentheses. Columns 2 and 4 report CP coefficients from a regression of the geographic variable on the CP indicator variable and a cubic spatial polynomial in $xy$-space. Observations are weighted by lot area. Heteroskedasticity consistent standard errors clustered at the block level are reported below the coefficient estimate in brackets. Levels of statistical significance are indicated as *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 


Table 5 also reports the CP coefficient from estimating Equation (6) with a cubic xy-polynomial for each geographic variable. By and large, the geographic variables do not exhibit discrete changes across the CP boundary. The one exception is the proportion of historical wetlands in the tax lot sample, which significantly increases across the boundary into the CP region. This relationship is driven by the presence of a natural salt marsh that existed on the east side of the sample in the area above present-day Houston Street. While these areas have since been drained or filled, it is plausible that they still affect contemporary outcomes due to flooding potential and construction complications related to the compressibility of the soil in these areas. I control for wetlands as well as the other indicators of physical geography to address this issue in the following analysis of economic outcomes.

Table 5 reports similar information for lot choices across treatment and control. While there is little difference across the CP boundary in terms of physical geography, the difference in demarcations regimes has direct effects on the characteristics of lots and their variation across space, implying that the CP has indeed affected demarcation decisions relative to LM. Direct

\[^{24}\text{The impact of historical wetlands is obviously more relevant to the historical sample, which does not exhibit a discrete change across the CP boundary. This is mainly due to a lack of vacant land observations below the CP boundary on the east side of the island.}\]
comparisons between samples are difficult to make because differences are likely due to both changes over time and selection effects. Nevertheless, some general patterns emerge from Table 5. Panel A of Table 5 reports means and differences across systems for lot area, fraction of irregular lots, and perimeter-area ratio.25 The top panel indicates lot level values. Most noteworthy is the significant reduction in irregular lots attributed to the CP across both samples. The CP also appears to reduce lot size and perimeter-area ratio in the contemporary sample.

To get a sense of the variation across lots, I calculate coefficients of variation within clusters for lot area and perimeter-to-area ratio. Clusters with only one observation are excluded. Panel B reports the means and CP coefficients. In general, the effect of the CP is to reduce variation across lots. The most significant decrease is seen in the variation in perimeter-to-area ratio in the contemporary sample.

**Historical and Contemporary Property Values**

Table 5 examines the impact of the Commissioners’ Plan on historical and contemporary property values and reports regressions coefficients for the CP

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25 Perimeter-area ratio is not reported for the historical sample because the area of irregular lots are calculated directly from the lot perimeter.
### Table 2: Lot Dimensions and Variation

<table>
<thead>
<tr>
<th></th>
<th>Vacant Land Sales</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1835, 1845)</td>
<td></td>
<td>(2013)</td>
</tr>
<tr>
<td><strong>A: Lot-Level Values</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (1000 sq. ft)</td>
<td>Mean (1)</td>
<td>CP Coefficient (2)</td>
<td>Mean (3)</td>
</tr>
<tr>
<td></td>
<td>1.8 (0.5)</td>
<td>0.5 [0.7]</td>
<td>6.1 (27.6)</td>
</tr>
<tr>
<td></td>
<td>Pr(Irregular)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.06 (0.23)</td>
<td>-0.15** [0.07]</td>
<td>0.31 (0.46)</td>
</tr>
<tr>
<td>Observations</td>
<td>345</td>
<td>345</td>
<td>16,843</td>
</tr>
<tr>
<td><strong>B: Within Cluster Variation</strong></td>
<td>Mean (1)</td>
<td>CP Coefficient (2)</td>
<td>Mean (3)</td>
</tr>
<tr>
<td>CoV Area (1000 sq. ft)</td>
<td>0.10 (0.12)</td>
<td>-0.43** [0.19]</td>
<td>0.97 (0.44)</td>
</tr>
<tr>
<td></td>
<td>Pr(Irregular)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.12 (0.13)</td>
<td>-0.06*** [0.01]</td>
<td>0.12 (0.13)</td>
</tr>
<tr>
<td>Observations</td>
<td>331</td>
<td>331</td>
<td>16,764</td>
</tr>
<tr>
<td>Clusters</td>
<td>55</td>
<td>55</td>
<td>869</td>
</tr>
</tbody>
</table>

**Note.** The above table describes lot characteristics from a historical sample of vacant land sales from 1835 and 1845 and 2012 tax lot data from Manhattan. Panel A reports values at the lot-level and panel B reports variation in lot values at the block-level. Columns 1 and 3 report mean values with standard deviations below in parentheses. Columns 2 and 4 report CP coefficients from a regression of the lot and block characteristics on the CP indicator variable and a cubic spatial polynomial in $xy$-space. Levels of statistical significance are indicated as *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 
indicator variable under increasingly diverse sets of control variables. All outcomes investigated are in logged per-area values. Panel A reports estimates for historical land values after controlling for year fixed effects. The specification in Column 1 is a pair-wise regression of CP on the outcome and the coefficient indicates the difference in the unconditional mean land values across the two areas. The estimate indicates land in the CP is 64 percent less valuable than land in LM on average. Since CP observations are farther from City Hall than LM observations, this result is consistent with the expected land-rent gradient from the monocentric city model. When controlling for distance to City Hall in Column 2, the relationship completely reverses so that the coefficient on CP is now equal to a 62 percent increase in land value. Column 3 controls for a quadratic polynomial in $xy$-space, column 4 controls for a cubic polynomial, and column 5 adds controls for physical geography to the cubic specification. Estimates from these specifications indicate a 20-28 percent increase in land value attributed to the CP and differences between estimates are statistically insignificant.
### Table 3: Historical and Contemporary Property Value

<table>
<thead>
<tr>
<th>Spatial control function</th>
<th>No Controls</th>
<th>Distance to CBD</th>
<th>Quadratic (x,y)</th>
<th>Cubic (x,y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV: ln(value/sq. ft)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>A: Land Value (1835, 1845)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>-1.01***</td>
<td>0.62***</td>
<td>0.28*</td>
<td>0.24*</td>
</tr>
<tr>
<td></td>
<td>[0.07]</td>
<td>[0.09]</td>
<td>[0.14]</td>
<td>[0.11]</td>
</tr>
<tr>
<td>Observations</td>
<td>345</td>
<td>345</td>
<td>345</td>
<td>345</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.16</td>
<td>0.70</td>
<td>0.76</td>
<td>0.80</td>
</tr>
<tr>
<td>Unlogged mean: $0.67/sq. ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B: Land Value (2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>0.64***</td>
<td>0.66***</td>
<td>0.17**</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>[0.08]</td>
<td>[0.16]</td>
<td>[0.09]</td>
<td>[0.07]</td>
</tr>
<tr>
<td>Observations</td>
<td>18,303</td>
<td>18,303</td>
<td>18,303</td>
<td>18,303</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.08</td>
<td>0.08</td>
<td>0.49</td>
<td>0.51</td>
</tr>
<tr>
<td>Unlogged mean: $134/sq. ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: Real Estate Value (2013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>0.84***</td>
<td>1.06***</td>
<td>0.27**</td>
<td>0.32***</td>
</tr>
<tr>
<td></td>
<td>[0.12]</td>
<td>[0.20]</td>
<td>[0.11]</td>
<td>[0.12]</td>
</tr>
<tr>
<td>Observations</td>
<td>18,303</td>
<td>18,303</td>
<td>18,303</td>
<td>18,303</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.09</td>
<td>0.09</td>
<td>0.45</td>
<td>0.47</td>
</tr>
<tr>
<td>Unlogged mean: $423/sq. ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sample radius | 2 mi | 2 mi | 2 mi | 2 mi |
| Geographical covariates | No | No | No | No |

**Note.** Table 5 reports regression coefficient estimates for the CP variable regressed on logged, per-area land and real estate values of lots within a 2-mile radius of the CP boundary. Panel A reports estimates on logged price per square foot from a pooled sample of vacant land sales in Manhattan from 1835 and 1845. Panel B reports current estimates for assessed land values and panel C reports current estimates for assessed real estate value. Observations are weighted by lot area. Heteroskedasticity consistent standard errors clustered at the block level are reported below the coefficient estimate in brackets. Levels of statistical significance are indicated as *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Pooled 19th century specifications control for year fixed effects.
Panel B reports estimates for contemporary land values. The CP coefficient is positive in all specifications and most are statistically significant at the 10 percent confidence level. Interestingly, the positive coefficient in column 1 shows that unconditional land values are now associated with the CP rather than LM, which suggests the historical central business district in Lower Manhattan has become a less significant driver of land values. Columns 3-5 estimate that the CP effect increases land values by about 20 percent which is generally consistent with the historical relationship nearly 200 years prior. Panel C reports estimates for contemporary real estate values. The estimates show a large and statistically significant CP effect, that is generally larger than the effect on raw land values.

If the observed differences in real estate values across the two regions are caused by the change in demarcation, it should also be the case that the magnitude of these differences correspond to the degree to which the demarcation patterns differ. It is relatively straightforward to see that demarcation change across the CP boundary is less stark on the east side of the island compared to the west, and therefore the effects should be attenuated on the east side. I therefore decompose the CP effect on property value in the
contemporary data between west and east sub-regions. I modify equation (6) to allow coefficients for the CP indicator, cubic polynomial, and control variables to vary by region. Specifically, I estimate

$$Z_{is} = \alpha_s + \theta_s CP_{is} + W_{is}' \beta_s + f_s(x_{is}, y_{is}) + \epsilon_{is}$$  \hspace{1cm} (7)$$

Table 5 reports estimates for the more flexible specification in equation (7) and for progressively narrower bands of observations around the CP boundary, in order to assess the robustness of the estimates. Each column reports coefficients for the total CP effect (row 1) and its component parts from the west (row 2) and east (row 3) regions. The estimated total CP effect increases real estate values around 30 percent and this estimate is relatively stable across the smaller samples. The effects are statistically significant at the 10 percent confidence level except in the 0.5-mile sample. The CP effect is considerably higher in the west than in the east, giving further support that the observed differences are explained by the change in demarcation at the CP boundary.

A similar analysis is not performed on the historical data set due to lack of power. The choice of discrete subregions is necessary given that the demarcation in the CP and LM differ on multiple dimensions. Without a larger sample of demarcation system variation, it is not possible to further decompose the effects of system characteristics into their component parts.
<table>
<thead>
<tr>
<th>Sample Radius</th>
<th>Real Estate Value (2013)</th>
<th>Building Density</th>
<th>Building Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 mi (1)</td>
<td>1 mi (2)</td>
<td>0.5 mi (3)</td>
</tr>
<tr>
<td></td>
<td>2 mi (4)</td>
<td>1 mi (5)</td>
<td>0.5 mi (6)</td>
</tr>
<tr>
<td></td>
<td>2 mi (7)</td>
<td>1 mi (8)</td>
<td>0.5 mi (9)</td>
</tr>
<tr>
<td>CP (total)</td>
<td>0.88*** [0.12]</td>
<td>0.60*** [0.14]</td>
<td>0.30 [0.19]</td>
</tr>
<tr>
<td></td>
<td>0.18*** [0.04]</td>
<td>0.11*** [0.04]</td>
<td>0.09 [0.06]</td>
</tr>
<tr>
<td></td>
<td>2.36** [1.03]</td>
<td>1.72** [0.77]</td>
<td>0.46 [1.02]</td>
</tr>
<tr>
<td>CP (west)</td>
<td>1.22*** [0.18]</td>
<td>0.73*** [0.23]</td>
<td>0.37 [0.33]</td>
</tr>
<tr>
<td></td>
<td>0.24*** [0.07]</td>
<td>0.11** [0.05]</td>
<td>0.12** [0.06]</td>
</tr>
<tr>
<td></td>
<td>2.17 [2.68]</td>
<td>3.23*** [0.80]</td>
<td>1.07* [0.62]</td>
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<tr>
<td>CP (east)</td>
<td>0.77*** [0.15]</td>
<td>0.55*** [0.16]</td>
<td>0.28 [0.23]</td>
</tr>
<tr>
<td></td>
<td>0.13*** [0.04]</td>
<td>0.09 [0.05]</td>
<td>0.06 [0.08]</td>
</tr>
<tr>
<td></td>
<td>3.04*** [0.99]</td>
<td>1.50 [1.01]</td>
<td>0.55 [1.38]</td>
</tr>
<tr>
<td>Spatial polynomial</td>
<td>Cubic</td>
<td>Cubic</td>
<td>Cubic</td>
</tr>
<tr>
<td>Geographic controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>15,615</td>
<td>11,472</td>
<td>8,001</td>
</tr>
<tr>
<td></td>
<td>15,615</td>
<td>11,472</td>
<td>8,001</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.51</td>
<td>0.58</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>0.49</td>
<td>0.49</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>0.53</td>
<td>0.51</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Note. Table 5 reports regression coefficient estimates for the CP variable regressed on logged real estate values per land area controlling for a cubic polynomial in $xy$-space and other geographic controls. Samples are divided into west and east regions corresponding to Figure 3. The top row of these columns reports estimates of the average treatment effect followed by estimates of the region-specific effects. mile radius of the CP boundary. Specifications in columns 1, 4, and 7 use the 2-mile sample, columns 2, 5, and 8 use the 1-mile sample, and columns 3, 6, and 9 use the 0.5-mile sample. Observations are weighted by lot area. Heteroskedasticity consistent standard errors clustered at the block level are reported below the coefficient estimate in brackets. Levels of statistical significance are indicated as *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 
Table 5 reports coefficients for the CP variable on a series of lot and building characteristics estimated from equation (7). Columns 3-6 report estimates for building density across the three sample radii. Building density is defined as the area of the building’s footprint divided by total lot area. The results indicate that there is a highly significant increase in building density in the CP. The total CP effect increases lot coverage by 9-18 percent across samples. The effect is even larger in the west sample where the increase in lot coverage ranges from 12-54 percent, which is roughly a 0.5-1 standard deviation change in building density. Furthermore, the progression of the point estimates across sample bands corresponds to the pattern of point estimates from the regressions on land and real estate values seen in Table 5.

Though higher building density indicates how efficiently ground space is being used, this result may reflect an increased willingness of landowners to invest capital in gridded parcels. Columns 4-6 of Table 5 report regression estimates in which building height—measured in number of floors—is the outcome of interest. The positive coefficients in columns 7-9 provide evidence that the CP also generates additional capital investment above and beyond the benefits gained at the ground level.
6 Conclusion

Substantial areas of urban land throughout the world are divided into systematic rectangular grids, and their increase in prevalence parallels the rapid development of land and real estate markets. In developing economies, where land is a fundamental asset, land markets represent a vital source of initial wealth accumulation and subsequent investment, particularly in areas with nascent financial markets. As was the case in New York City, real estate entrepreneurs and speculators were the primary financiers of land sales, improvements, and infrastructure before the city’s financial institutions had matured. It follows that the efficiency of land markets can have profound effects on the trajectory and ultimate fate of a developing economy.

As shown in this study, decentralized land demarcation systems have the potential to inhibit development by increasing transaction costs associated with the use, development and exchange of land. The centralized and uniform institutional structure of rectangular grids appears to reduce these frictions to facilitate growth. Important questions remain on the full impacts of land demarcation institutions, and more comprehensive studies on the general equilibrium effects of gridded urban plans and their implications for public infrastructure and transit can provide important complements to these find-
ings. Such studies add to a growing recognition of the broader links between institutional quality, geography, and economic outcomes, and evidence provided in this paper suggest that the spatial institutions governing land use are an important channel in this relationship.
References


Chapter 2 Appendix: Variables and Data Sources

**Taxlot Data** Data on contemporary Manhattan tax lots are taken from the MapPLUTO spatial database created by the Department of City Planning in New York City. Some data is aggregated from other sources including data on assessed raw land value and assessed total real estate value which are established annually by New York City’s Department of Finance for tax purposes.

**Lot Type** Lot type is taken from the MapPLUTO database and indicates a tax lot’s relationship with neighboring features as assigned by the Department of City Planning. Waterfront lots border on a body of water and may contain a small amount of submerged land.

**Vacant Lots** Vacant lots are indicated in the MapPLUTO database as a type of land use assigned to a tax lot by the Department of City Planning.

**Assessed Land Value** Assessed land value is a tentative value assigned by the Department of Finance for Fiscal Year 2013 and is taken from the MapPLUTO database. The Department of Finance calculates assessed value of a tax lot by multiplying the tax lot’s estimated full market land value, determined as if vacant and unimproved, by a uniform percentage for the property’s tax class.

**Lot Area (contemporary sample)** Lot areas represent the area of a tax lot calculated in GIS from the MapPLUTO shapefile.

**Lot Area (historical sample)** Lot areas are calculated using the dimensions listed. Rectangular lot areas are calculated by multiply the two dimensions listed. Irregular lot areas are calculated as the area of a circle with a circumference equal to the perimeter of the irregular lot.

**Building Footprint Area** Building area is calculated in GIS from a geodatabase of building footprints in New York City made publically available by the Department of Information Technology and Telecommunications (DoITT) and downloadable from https://nycopendata.socrata.com/.

**Building Density** Building density is calculated in GIS by linking buildings to tax lots and then calculating total building footprint area dived by lot area.

**Building Height** Building height is calculated from the number of building floors times a constant floor height, which I assume to be ten feet. Data on number of floors is taken from the MapPLUTO database and is originally assigned by the Department of Finance in their RPAD Master File.
number of floors only refers to the primary building on the tax lot.

**Building Volume Density** Building volume density measures building footprint multiplied by building height divided by lot area.

**Topography** Elevation data is collected from Digital Elevation Models (DEM) in the USGS National Elevation Dataset. The DEMs are in raster (grid) format with each 30 minute (approximately 10 meters) cell reporting an elevation value. A raster measuring surface slope is created by calculating the average slope angle between neighboring cells based on differences in elevation.

**Historical Wetlands** Marshland is defined using data from the eco-communities raster data set created as part of the Manhatta Project. Cells classified as marshes include areas identified as marshes, swamps, bogs, or mudflats.