# The Effect of Checkerboard Land Ownership Pattern on Land Markets

By

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**STATEMENT BY AUTHOR**

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# ABSTRACT

In this thesis I examine the effect of a constraint on land configurations using two different property rights regimes- checkerboard and non-checkerboard lands- on land markets. The checkerboard land ownership pattern refers to alternating section pattern of public and private lands created by the railroad land grants of the late nineteenth century. Given the rectangular survey (RS) grid of the United States, each 640 acres (1 square mile) section of private land inside checkerboard in surrounded by public land on all four sides. Similarly, every section of public land inside the checkerboard is surrounded by private land on all four sides. I develop an economic framework for conducting comparative analysis of private lands inside and outside the checkerboard. I begin by considering how a private landowner inside the checkerboard achieves optimal acreage compared to a private landowner outside the checkerboard. I develop five measures of "checkerboardedness" to account for depth and extent of the checkerboard. My primary hypothesis is that areas with higher values of checkerboard measures have lower land values per acre and create fewer incentives for landowners to invest in the land. My empirical analysis focuses on Douglas County, Oregon where private lands are present in and outside the checkerboard. Checkerboard lands in the area were a result of Oregon and California Railroad land grant of 1866. I use Douglas County Tax Assessor data for year 2013 to compare land values for land sections inside and outside the checkerboard. A section as defined by the rectangular survey of the United States is the unit of observation. The empirical estimates indicate that checkerboard lands have lower land values per acre and lower private roads density compared non-checkerboard lands, all else equal.

# CHAPTER 1. INTRODUCTION AND RESEARCH QUESTION

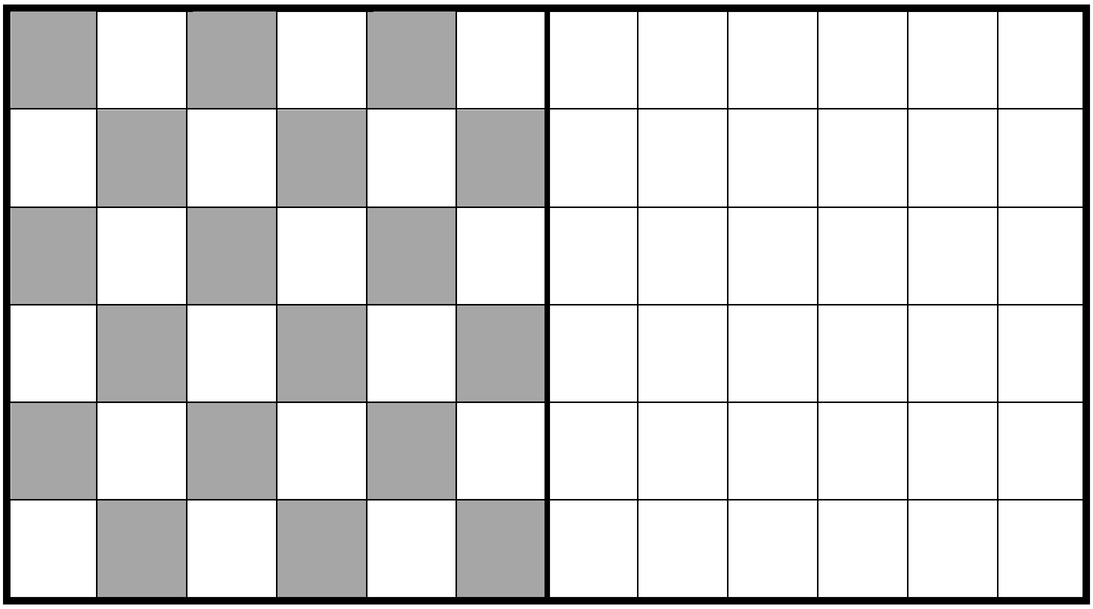
## 1.1 INTRODUCTION

Property rights regimes, ranging from private property to open access, provide an insitutional structure for individuals to interact with each other and their environment. Each regime type entails a unique system of property rights and thus, presents different incenctives and opportunities for individuals to maximze the value of their assets [1]. Coase (1960) suggests that the initial allocation of property rights is inconsequential to the efficiency of the final outcome in absence of transaction costs. This outcome, however, might be hindered in the presence of transaction costs (Coase 1960). The striking persistence of checkerboard landownership pattern in the Western United States presents a setting to study the effect of an ownership structure created in the nineteenth century on land markets.

In this thesis I examine the effect on a constraint on landownership by comparing economic outcomes of two - checkerboard and non-checkerboard (consolidated private lands) – land ownership patterns. In a checkerboard, privately owned land sections (640 acres) are surrounded by public sections on all four sides and each public section is surrounded by private land on all four sides. In the non-checkerboard area, privately owned land sections are surrounded by privately owned sections on all four sides. I provide the analysis using a pseudo natural experiment setting, created by nineteenth century land policy, in which public and private lands were placed adjacent to one

[1] Property rights, in economic terms, are defined as the expected ability of an economic agent to use an asset. This includes the right to consume, obtain income from, and the right to transfer all or some rights to the asset to another person (Brazel (1989); Lueck and Miceli (2007; G. Libecap (1989); Besley and Ghatak (2010)).

another in a checkerboard landownership pattern. The railroad land grants conveyed to the railroads the rights to the odd-numbered sections of land on both sides of the railroad, the exact number of sections varying from one grant to another. The even-numbered sections were retained as public property. Thus, each private section in the checkerboard was surrounded by public lands on all four sides and each public section was surrounded by private lands on all four sides. Figure 1 presents a visual schematic showing checkerboard and non-checkerboard panels adjacent to each other. Each square represents a section (640 acres). Private and public lands are shown in white and grey color respectively. Panel A shows checkerboard landownership with alternating public and private land sections. All sections in Panel B are privately owned. Despite a number of land exchanges in recent years, the checkerboard landownership pattern is persistent in some parts of the Western United States. This setting provides a unique context to study the economic consequences of a historial event, the effects of which are persistent till today. Looking at surface ownership status maps, I identified viable study areas in Oregon, Arizona, Nevada, Wyoming and California that may be pursued at a later date (See Appendix B for landownership status maps for Arizona, Nevada and Wyoming). Due to the interest in Oregon checkerboard, the economic value of timber, and presence of consolidated private lands adjacent to checkerboard lands, Oregon was selected for analysis. The empirical setting for this thesis is Douglas County, Oregon.



PANEL A PANEL B

**Figure 1-1 Schematic showing checkerboard and non-checkerboard lands in rectangular survey.**

Clearly defined property rights provide incentives for owners to maintain and invest in assets. Moreover, there is consensus on the importance of clearly defining property rights for economic efficiency and economic development (Besley and Ghatak 2010). Land titles enhance land values as they reduce insecurity, provide collateral for investments, and facilitate land markets. Lee, Libecap and Schneider (1996) show that the land titles in Brazil led to increase in land values and investment. Libecap and Lueck (2011) compare a variety of measures to analyze the economic effects of two dominant land demarcation regimes, meters and bounds (MB) and the rectangular system (RS), and find that there are large initial benefits in land values under the RS system and that these benefits persist more than one century and a half later.

Private landownership creates incentives for use and investment to enable the landowners to efficiently maximize the land value. The optimal boundary requirement, however, varies with land use. It is possible that the optimal land size for a particular land use exceeds existing property boundaries (Lueck and Miceli 2007)[2]. In this situation, one option is for the landowners to negotiate a contractual agreement that internalizes the externalities. The second option is for landowners to consolidate ownership of the parcels, thus altering the parcel size owned by each (Demsetz 1967). Which option is chosen depends on the transaction costs involved. The number and heterogeneity of the landowners involved (expectations, costs, wealth, size), the information that they hold, and the physical nature and value of land are criticial factors that determine the transaction costs involved (G. Libecap 1989). Thus, the presence of transaction costs determines the nature of the land market.

## 1.2 RESEARCH QUESTION

The goal of this study is to examine the effect a constraint on land configuration on economic outcomes. I use two alternate property rights regimes-checkerboard and non-checkerboard lands- to examine my research question. Checkerboard landownership pattern, created by the nineteenth century railroad land grants, provides an interesting setting to compare two- checkerboard (alternating public and private lands) and non-checkerboard- property rights arrangements. In this thesis, I examine the effects of the checkerboard landownership pattern on land values in Douglas County, Oregon. In the original checkerboard landownership pattern created by railroad land grants, a 640-acre section of private land in checkerboard was surrounded by public land on all four sides.

[2] For some activities, like grazing and mining, typically larger areas are required than optimal size requirement for agriculture (Ellickson 1993).

Similarily, each 640-acre section of public land was surrounded by private land on all four sides. Over the years, however, checkerboards have been eroded. Since the initial distribution of land was an exogenous process, independent of land characteristics, checkerboards provide a pseudo natural experiment setting. The primary hypothesis is that lands inside the checkerboard have lower land values than comparable lands outside the checkerboard.

This study contributes to the existing literature in at least four ways. Firstly, my analysis contributes to a growing literature that studies the effects of early property allocations that persist years after the initial allocation. Secondly, it addresses the measurement issues that stem from endogeneity of initial property rights allocation. The checkerboard landownership pattern in Douglas County is reminiscent of the Oregon and California railroad land grant. Although, some lands have exchanged hands, the initial allocation of property rights was exogenous. Irrespective of land quality characteristics, odd numbered sections were awarded to the railroads and even numbered sections were retained by the federal government. Thirdly, this contributes to the burgeoning literature that studies the effects of spatial features on land values. Not only does the distribution of an owner's landholding and land uses in the neigborhood affects land values, but also the inability to expand one's landholding adversely affects the landvalues. Lastly, this thesis provides first empricial analysis of the effects of checkerboard land ownership pattern. To be clear, checkerboard land ownership and fragmented ownership refer to two distinct phenomenon. In a checkerboard land ownership pattern, each private land section is surrounded by public land on all four sides and vice versa. Fragmented ownership refers to phenomenon where a single owners' landholding is divided into several plots. A fragmented ownership, however, could exist in a checkerboard pattern. To my knowledge, no peer reviewed study empricially tests the loss in value from checkerboard land ownership pattern. Moreover, given the increased discussion of land exchanges in recent years, this study illustrates the costs of ownership in checkerboard.

An economic framework is developed to study the impact of an individual landowner's inability to change his/her land configuration. I argue that a privately owned land section located inside the checkerboard, surrounded by public land on all sides, has lower land value than a comparable land-quality privately owned section that has private land on at least one side.

Checkerboard lands provide an interesting setting to further examine the effects of a constraint on land configuration, where historical events have created a landscape in which checkerboard and non-checkerboard lands exist adjacent to each other. In the checkerboard, land titles and land demarcation system, based on relevant literature, is favorable to higher land values.Therefore, property rights are clearly defined inside and outside the checkerboard. The ownership of each section in checkerboard is clearly established and the sections are demarcated using the RS system. The land configuration inside the checkerboard, however, cannot be modified easily. The checkerboard landownership pattern thus impacts the private land markets by increasing transaction costs.

## 1.3 ORGANIZATION OF CHAPTERS

This thesis is organized as follows. In chapter 2, I describe the history of railroad land grants and the resulting creation of checkerboard landownership patterns in Western

United States. An economic framework for analyzing the consequences of checkerboard pattern of ownership on land values is developed in chapter 3, along with hypothesized effects of this arrangement on land values. This is followed by discussion of sample description, data and empirical strategy in chapter 4. Conclusion and questions for future research are discussed in chapter 5.

# CHAPTER 2. RAILROAD LAND GRANTS AND THE EVOLUTION OF CHECKERBOARD LAND PATTERNS

In this chapter, I discuss the history of railroad land grants and the creation of checkerboard landownership pattern. The history of railroad land grants can be divided into three main periods: 1) the land grants to states (1850-1857) 2) the land grants to transcontinental railroads (1857-1971) 3) the forfeiture of the land grants (1876-1890). To understand the impact of a land ownership arrangement created in the nineteenth century on present day land values, it is imperative to understand the history of railroad land grants and associated land policy. A number of authors discuss the impact of railroad land grants on the economic development of the West including Atack, et al. (2009), Coffman and Gregon (1998) and Craig, Palmquist and Weiss (1998). The following section, however, focuses on arguments for and against railroad land grants followed by a discussion of the structure of railroad land grants.

## 2.1 EARLY LAND GRANTS AND LAND POLICY

Before 1830, turnpike and waterways provided the main means of transportation and trade communication. Railroads were considered supplemental, used only in areas where waterways were inaccessible or canal improvement was impossible (Sanborn 1899). Therefore, long before the advent of the railroad land grants, the United States government used federal lands to aid states carry out internal improvement projects such as river improvement, canal and wagon-road construction. The right of way through public land was often included in earlier grants, but such grants carried no extra donation of lands (Greever 1951). The grants for wagon roads made during and after the civil war, however, also included land donations (Gates 1969).

By the mid-nineteenth century, the demand for railroads was growing in the West. The eagerness to provide a connection between east and west provided additional impetus to develop the West as rapidly as possible. In addition, discovery of gold in California in 1848 led to an increase in the settlement of the West (Paul 2006). Also, the new states favored the use of public domain to support internal improvement projects to compensate for lost tax money (Mercer 1982). At this time, United States government owned approximately 1.46 billion acres of unoccupied and vacant land (Henry 1945). Before 1850's, a number of bills were proposed in favor of the railroad grant. These included the proposition of granting alternate sections of land for a railroad. It was suggested that construction of railroad would result in increased sale of the public lands. Moreover, it was suggested that lands should be granted in an unsettled part of the county to create demand for these lands (Sanborn 1899). In 1850 Stephen A. Douglas and John Wentworth succeeded in pushing Congress to pass grant for a railroad that included land grant along with rights-of-way. Douglas pointed out that lands in the proposed areas of Illinois, Mississippi, and Alabama had been on market for 23 years but had not sold. Moreover, he suggested, that the government would lose nothing if it retained ownership of half the sections within the 6 miles strip and raised the price of retained land by 100 percent[3]. Thus, railroad land grants distributed lands in a manner that created the checkerboard lands (Gates 1969). At that time, the government viewed itself as the

[3] The first grant, Chicago and Mobile Act, granted states of Illinois, Mississippi, and Alabama, a 100-foot right of way and even numbered sections within 6 miles of the railroad. After 1853, the railroad land grants shifted from even numbered sections to odd-numbered sections to avoid loss of sections 16 and 36. (Gates 1969)

custodian of public land and aimed to transfer public land into private hands. Thus, the checkerboard of public and private landownership was not a serious concern for the policy makers at that time (Paul 2006).

After the Land Ordinance Act of 1785, the Rectangular Survey (RS) system was implemented. Under the US Rectangular System land is divided into six mile by six-mile square townships with north-south lines intersected by perpendicular east-west lines. Each township is further divided into 36 sections, each 1 mile square is numbered from 1 to 36, starting with 1 in the northeastern section and running north to south in each row up to 36 in the southeast section. Figure 2-1 shows the rectangular survey system in the United States along with principal meridians and baselines. Panel A in Figure 2-2 shows the principal meridian for Oregon, the Willamette Meridian, extending from north to south from the initial point. Base line is extending from the initial point in east and west direction. The structure of townships and sections is shown in panel B and C. At the time of railroad land grants, Oregon was already demarcated using the RS system (Hubbard 2009).

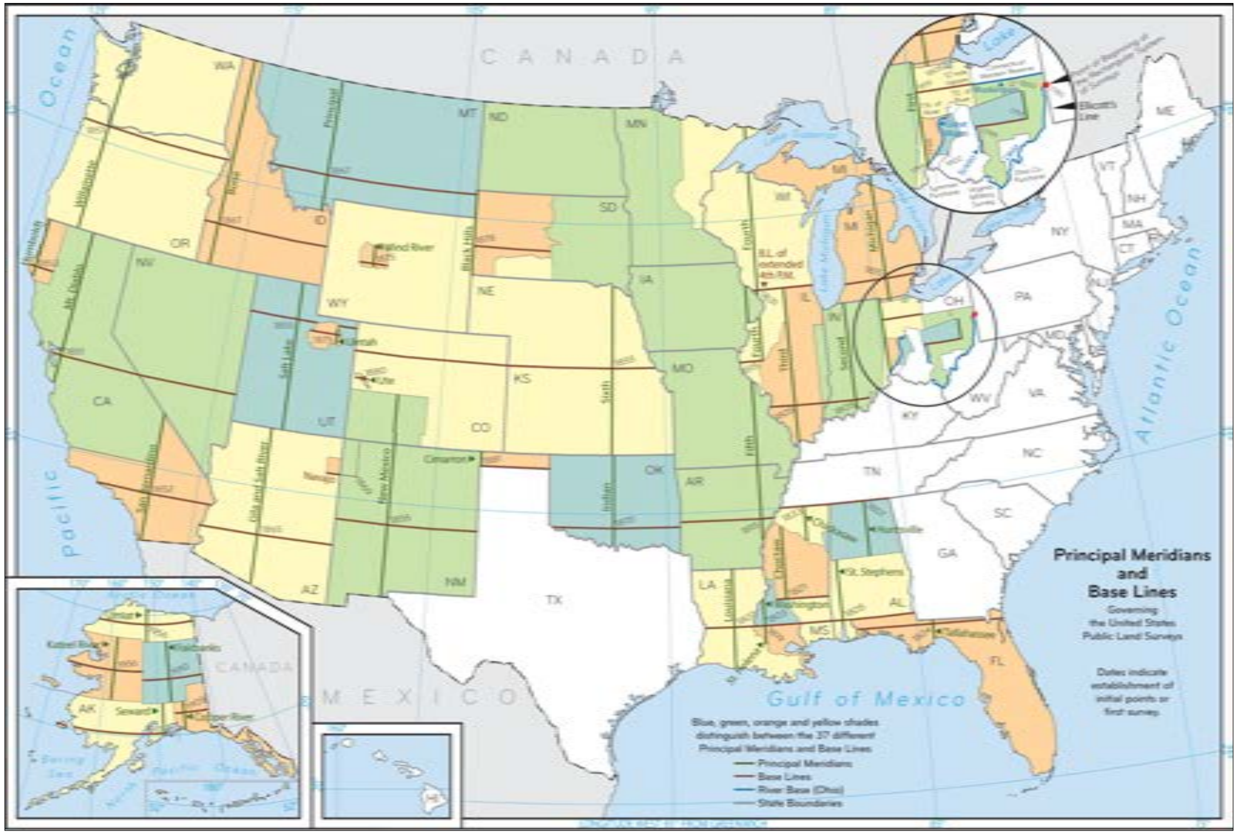
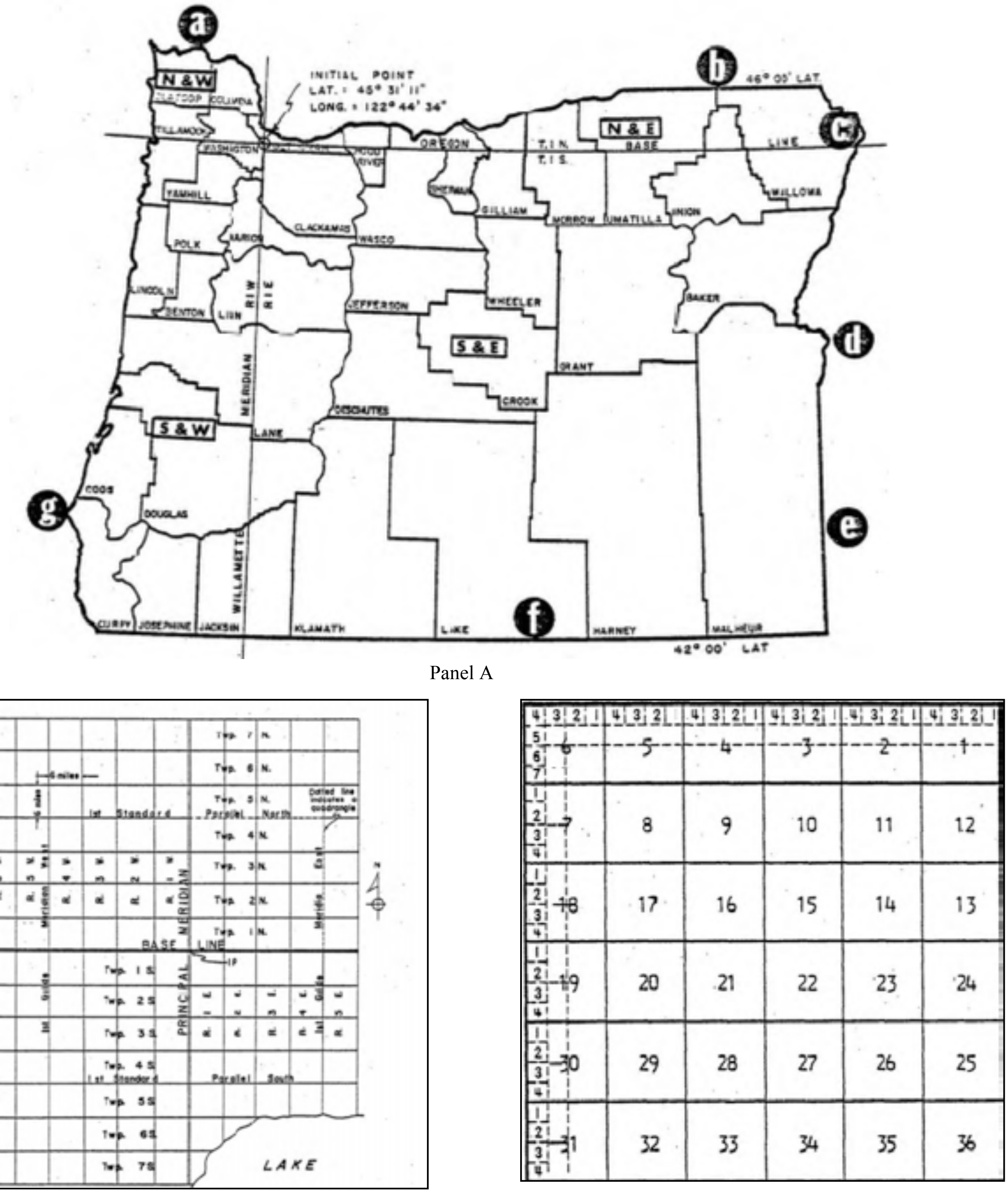



**Figure 2-1 Rectangular Survey in the United States**

Source: Bureau of Land Management (http://www.blm.gov/wo/st/en/prog/more/cadastralsurvey/meridians.html)




Panel B

Panel C

**Figure 2-2 Rectangular Survey in Oregon**

Source: Oregon Cadastral Map System

Later land grants to the railroads followed a similar structure. Mostly, the odd-numbered sections lying on either side of the railroad for 6 to 40 miles, the exact distance varying from one grant to another, were awarded to the railroads.  These were called the "primary lands". The legislation also included a clause that retained public land was to be sold at double the minimum price, thus earning as much money as if the land grant had never been made. Also, the acts provided "lieu lands" that extended for 9 to 20 miles, located immediately adjacent to the outer edges of the primary lands. The purpose of these lieu lands was to allow railroads to pick replacements for the alternate sections that had already been sold of before the primary lands were reserved for the company (Greever 1951). Thus, the railroad land grants involved three types of land: the right of way, the primary or base lands and indemnity or lieu lands (Swenson 1957). Figure 2-3 shows a map from the 1932 Atlas of the Historical Geography of the United States that reveals the United States land grants available for the construction of railroads and wagon roads between 1823-1871. As the key indicates, dark lines represent the limits of the land grants. Hatched areas show forfeited railroad grants. It is important to highlight that the land grants did not give away the lands. The railroads earned sections by actual construction of the railroad. After 25 miles of line was accepted as satisfactory by government inspectors, proportionate acreage was deeded to the railroads. Moreover, the federal government got reduced rates from the companies. With a few exceptions, the companies charged federal government 80% of regular rates for mail and 50% for all other traffic (Greever 1951).

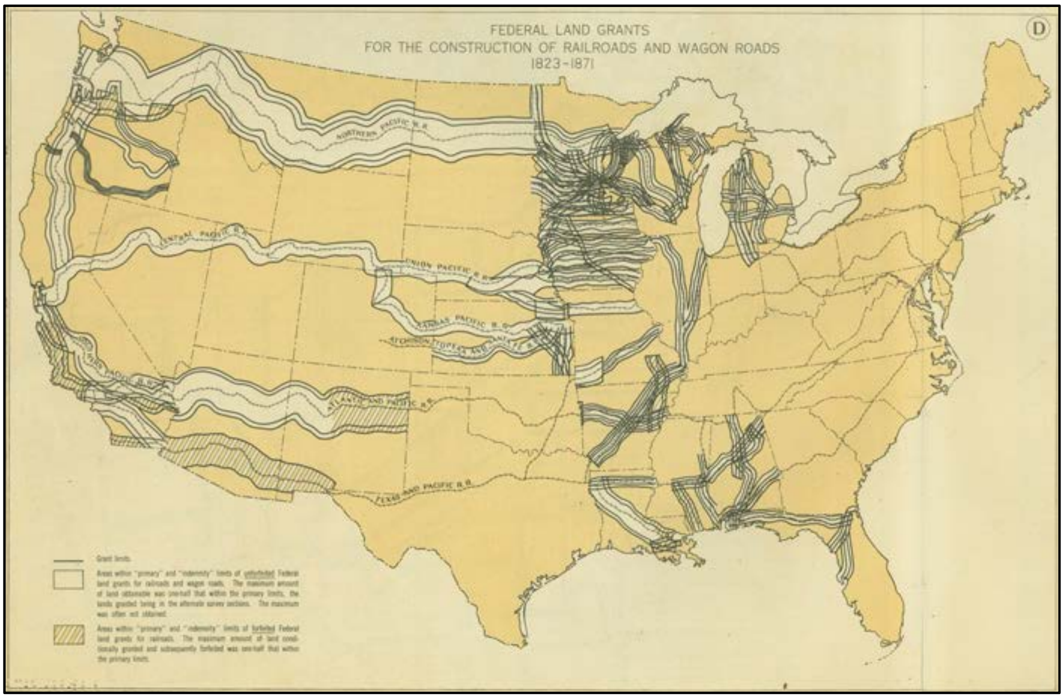



**Figure 2-3 Federal Land Grants Between 1823-1871.**
Source: “Railroads and the Making of Modern America”, http://railroads.unl.edu/documents/view_document.php?id=rail.str.0239

## 2.2 TRANSCONTINENTAL RAILROADS

After the railroad land grants to the states and in period leading to the civil war, the question was to decide a route for construction of a transcontinental railroad connecting the Midwest and the Pacific Coast. The states in South wanted that at least one transcontinental railroad should be constructed along a southern route (Greever 1951). After seeing the disastrous result of extending grants to the states, most grants in later years were extended directly to the corporations. These started with the Pacific Railway Acts of 1862 and 1864, which awarded lands to the Central Pacific, Union Pacific and others. These grants, in addition to the right of way and land grant, allowed companies to take timber and stones from public lands. The idea was that private companies would use the grant lands to finance the construction of the railroad. The public in the land grant areas wanted the land to be sold quickly (Gates 1969). The railroads, however, typically found it more profitable to sell the land to large timber and mining corporations or to mortgage the land to its own subsidiaries. For a number of reasons including scandals of fraud and corruption, failure to meet completion deadlines, the increasing resentment about delay in selling railroad lands, by the end of the nineteenth century, the US government had committed itself to retaining the lands (Paul 2006). The last land grant was made to the Pacific Railroad Company in 1871 after which the change in public opinion prevented future grants. These grants to the transcontinental railroads comprised about 77% of total acreage granted via the railroad land grants (Mercer 1982). [4]

## 2.3 OREGON AND CALIFORNIA RAILROADS

This section discusses the Oregon and California Railroad land grant that resulted in creation of the checkerboard lands in my study area, Douglas County, Oregon. In the later half of the nineteenth century, as the transcontinental railroad network was growing, there was demand for a connection between California and Oregon to facilitate the lumber trade. The first land grant in favor of a railroad connecting Oregon to counties in California was passed in July 1866 (Act of July 25, 1866, Ch. 242, 14 Stat. 239)[5]. According to this act the state of Oregon, acting on behalf of the government, was to

[4] The Canadian government followed a similar land grant policy to aid the construction of railroads. In 1871, after the admission of British Columbia into the confederation, the Canadian government promised to provide British Columbia a connection via rail to rest of the country. In 1879, the government offered $25,000,000 cash subsidy and 25,000,000 acres of land to aid the construction of the Canadian Pacific Railway. Instead of offering a certain number of acres for each mile of railroad constructed, the Canadian government set a specific quantity of land for the railroad grant. It allocated alternate sections of land that were considered 'fairly fit for settlement' in a 24 mile belt on either side of the railroad track to satisfy the grant (Greever 1951).

[5] Checkerboard lands were also created by the land grant for construction of Coos Bay Wagon Road (1869). This road was supposed to provide a link from Roseburg to the sea and facilitate movement of troops and their supplies. In Coos and Douglas counties about 105,000 acres of land were made available for this grant. (Richardson 1980). Coos Bay lands were revested in 1919 (Tuchmann and Davis 2013).

transfer approximately 12,800 acres of land for each mile of track laid between Portland and Siskiyou Mountains (Bureau of Land Mangement n.d.). The land grant set aside odd numbered sections (640 acres each) that were not homesteaded and non-mineral in nature, in twenty miles strip on both sides of the right of way[6]. As many sections in the area were already occupied, the grant recipient could select alternate sections from ten miles track of indemnity lands. Essentially, the designated railroad company could select sections within a sixty-mile wide corridor along the right of way (Richardson 1980). Figure 2-4 shows the resulting pattern of checkerboard landownership created in Douglas and Coos County.

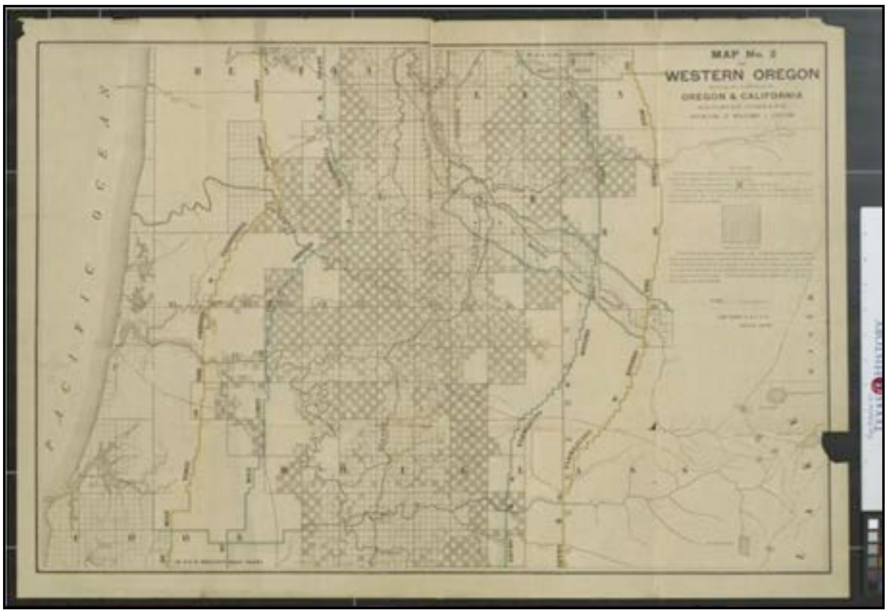



**Figure 2-4 Map of Western Oregon showing lands of Oregon and California Railroad Company.**
Source: (http://texashistory.unt.edu/ark:/67531/metapth252074/: accessed February 10, 2014), University of North Texas Libraries, The Portal to Texas History, http://texashistory.unt.edu; crediting University of Texas at Arlington Library, Arlington, Texas.

[6] Primary lands along the Willamette had already been occupied by homesteaders since the 1840's. Also, speculators had purchased lands along the proposed railroad so by the time railroad company filed its map showing a definite route, much of the acreage in primary lands had already been lost (Ellis 1948).

The Oregon Central Railroad Company was designated as the proper recipient of the land grant by the state legislature. The company proposed to construct a railroad from Portland to the southern border of Oregon. A year later, however, another company by the same name was created to construct in the same direction but on the east side of the multi-river system (Richardson 1980). In 1869, the two companies merged to create the Oregon and California Railroad Company. Another grant was passed in 1869 to extend the completion time for the railroad (Act of April 10, 1869, 16 Stat. 47). This time, however, the grant included three new clauses that were not part of the initial land grant. The railroad could only sell lands to 'actual settlers', sales could only be made of 160-acre section and the railroad could only charge a maximum price of $2.50 per acre (P. G. Dodds 1986-87). The grant was given to the Oregon and California Railroad Company (O&C Company). In 1870, another grant was made for the construction of railroad from Portland to Astoria, in addition to a branch line from Forest Grove to the Yamhill River near McMinnville. According to this land grant, railroad could receive alternate sections within ten miles on each side of the proposed railroad (Ellis 1948). In 1873, however, O&C Company defaulted. Finally, the Southern Pacific leased the O&C from 1887 until the railroad to California border was completed in 1927. Figure 2-5 shows the railroad land grant lands in Oregon. Oregon and California lands are shown in grey and Coos Bay Wagon Road lands are shown in black color. See appendix for checkerboard landownership maps for the state of Oregon over time.

Before 1887, the railroad company had only sold about 163,000 acres of grant lands, as most of the land was not suitable for farming and timber was not valuable at that time. As timber prices began to rise, however, the demand for these lands increased (Ballaine 1953). By 1908, approximately 813,000 acres of land had been sold with 515,000 acres violating one of the terms of the O&C land grant (Ellis 1948). In clear violation of grant terms, the railroad company was selling large tracts of land to a few purchasers at prices that went up to $40 an acre (Richardson 1980).

By the end of the century, there was major change in the national policy regarding public lands (Gates 1969). In 1891, the first national forests were established. This further increased the prices of timberland in Oregon, providing another profitable opportunity for the railroad company. At this point, the Oregon and California grant lands were concentrated in five southwestern counties of Oregon including Coos, Douglas, Josephine, Jackson and Lane counties. Compared to Multnomah County (where Portland is located), which had only 4,285 acres of grant lands, Douglas County had over 650,000 acres. In July 1913, after numerous complaints about the railroad company's practices, the court decided that the railroad company could retain ownership of lands for which the title had been transferred but unsold grant lands were forfeited (Richardson 1980). At this time, the unsold land was steep-sloped and unsuitable for farming, however, was covered with Douglas- fir trees (Gates 1969). Congress passed the Chamberlain-Ferris Act in 1916 reclaiming about 2.4 million acres of unsold O&C lands to public ownership (Act of June 9, 1916, Ch. 137, 39 Stat. 239). According to this act, timber and land were to be treated separately and timber was to be sold as quickly possible. Then, the logged lands were to be made available for homesteading at $2.50 per acre. Timber in this area, however, was not as easily or cheaply accessible as in other parts of the state[7]. Thus, the sales were slow (Blumm and Wigington 2013). This act, however, did not provide financial support to counties in the area to meet their school and port obligations. Thus, the O&C act of 1937 (Act of August, 28, 1937, 50 Stat. 876) was passed. According to this act, the management of the O&C lands was to remain the responsibility of the Department of Interior. The responsibilities included: managing the forest production in conformity with the principle of sustained yield, fix allowable cuts of timber, contribute to local economic stability, and to distribute receipts from timber sales to O&C counties and to the federal treasury. In 1956, to resolve management challenges, Congress authorized the Forest Service and the BLM to exchange 241,000 acres of land to consolidate holdings (Bureau of Land Mangement n.d.). Table 2-1 shows the Oregon and California Lands timeline.

[7] The O & C timber sold slowly because the land was remote particularly in light of the facilities available to transport timber. Second, the O&C track was only 640 acres in size therefore, very few operators were interested in logging such a small area unless they could log neighboring private or forest lands as well. Lastly, the Department of Interior was careful to avoid selling timber at below market prices (Ballaine 1953). Initially, Lumbermen were attracted to Puget South region in Washington as timber could be transported easily in the area (Ellis 1948).

**Table 2-1 O&C Lands Timeline**

| | |
|---|---|
| **1866** | Land grant to construct railroad between Portland, Oregon and California. |
| **1869** | Land grants terms revised to include homesteaders' clause. |
| **1916** | Chamberlin-Ferris Act- O&C Lands Revested |
| **1937** | O&C Act- Sustained yield and payment to Oregon counties |
| **1953** | O&C counties share reduced to 50% to fund the development and management of O&C lands by the government. Plow back fund created to support road construction, timber management, and reforestation. |
| **1976** | Federal Land Management and Planning Act (FLPMA) |
| **1982** | Congress made administration of O&C lands part of BLM appropriations. |
| **1994** | Northwest Forest Plan to provide stable supply of timber and protect wildlife habitats in Western Oregon, Western Washington and Northern California. |

Source: Adapted from Tuchmann and Davis (2013) and (Bureau of Land Mangement n.d.)

## 2.4 LAND POLICY REGARDING CHECKERBOARD LANDS TODAY

By the end of the nineteenth century the United States government shifted to a policy of retaining public lands in federal ownership. Before 1980s, the Forest Service and Bureau of Land Mangement, preferred to buy land by making payment using cash.With shortage of funds available to buy lands, however, both agencies have used land exchanges to consolidate landownership patterns to facilitate efficent resource mangement. In 1976, the Congress enacted the Federal Land Policy and Management Act (FLPMA) to facilitate land exchange between federal agencies (the Forest Service and Bureau of Land Management) and nonfederal landowners including corporations and private landowners. FLPMA provides the statutory basis for land exchange and includes procedures that Federal agencies need to adhere to during land exchange. The two fundamental requirements that these agencies must follow are: first, the estimated values of land must be equal or approximately equal[8]. Second, the agency involved must determine that the public interest is well served by the land exchange[9].

From the very beginning, it was expected that government would facilitate land exchange to support timber sales (Richardson 1980). According to the findings shared in the Oregon Land Exchange Act of 2000, exchange of private and public lands was proposed to facilitate efficient management of both public and private lands. Moreover, the improvement in management efficiency was expected to improve public access and recreational opportunities, facilitate administration by BLM and USFS to reduce administrative costs, and to reduce special use and other permit processing costs (Government Printing Office 2008). In examnining land exchanges in Northern Rockies, Kmon (1999) finds that the lack of access is a serious concern for landowners in the checkerboard. Of the eight land exchanges examined by Kmon, four land exchages citied inability to access land as one of the motivations behind exchange. Another problem was the presence of significant administrative costs due to extensive property boundaries. Forest Service mentioned the costs of surveying, marking, establishing corners, and administrative costs as a motivating factor behind the land exchanges. Second to protection of sensitive species habitiat, consolidating land ownership was the most mentioned purpose for land exchange followed by the need to provide access to timber

[8] The estimated values can be equalized by cash equalization payment which cannot exceed 25 percent of federal land's estimated value. Generally, appraisals are used to estimate values of lands proposed for exchange.

[9] This includes conformation with the needs of the State and local people, the economy, community expansion, recreation, fish, wildfire, etc. Moreover, the agency needs to demonstrate that the benefits from exchange will match or exceed the benefits from retaining the federal land. Also, the agencies are required to complete an environmental analysis under the National Environmental Policy Act for each exchange, in which the public interest is identified and analyzed. Other requirements include that exchanged lands must be in the same state, titles for exchanged land must be transferred simultaneously, and land acquired within the boundaries of national forest service, national park system or any other land system immediately become part of the system and managed accordingly. Land exchanges can be initaited by the interested federal agency or by nonfederal party/parties. For the land exchanges between 2004 and 2008, the Government Accountability Office found that time to process land exchange varied from 2 months to 12 years (GAO 2000). Typlically, the federal and nonfederal parties equally share the administrative costs for an exchange that include the cost of the appraisal of land, mineral examinations, cultural resource survey etc. (Vincent 2007).

companies. Based on the environmental documents, forest services reported $737,000 savings over a 10 year period for the Kootenai Nation Forest exchange (Kmon 1994).

# CHAPTER 3. ECONOMIC ANALYSIS OF CHECKERBOARD LANDS

In this chapter, I develop an economic framework to examine the effects of checkerboard landownership pattern on land market and related issues. In particular, I analyze how presence of checkerboard pattern of land ownership alters the incentives for private landowners inside the checkerboard and its impact on economic performance. In the following sections, I conduct analysis by focusing on land values and incentives to invest in land.

In recent years, a number of studies have looked at the impact of historical events on present day outcomes. Libecap and Lueck (2011) explore the effects of two land demarcation regimes, metes and bounds (MB) and rectangular survey (RS), on economic outcomes. They find large benefits in land values from the RS and these benefits persist a century later. Bleakley and Ferrie (2014) measure the effect of initial parcel sizes on the evolution of farm sizes decades after initial property rights assignment. They find that initial parcel sizes predict farm sizes for 50-80 years after land opening, and these effects only disappear after 150 years.

Also, many studies explore the impact of land fragmentation on economic efficiency and productivity of farms. Land fragmentation, used interchangeably with parcelization, refers to a phenomenon where each owner's land is divided into many small farms. From an economic perspective, land fragmentation could have both positive and negative effects. Firstly, fragmentation may exacerbate conflicts regarding labor allocation on the land. A more fragmented landholding would mean that labor force wastes time traveling from one plot to another that could have been used to undertake more productive tasks. Moreover, landowners would need to invest in extra roadwork and road safety measures to facilitate labor movement between plots. Secondly, a fragmented landholding may entail higher production costs as additional equipment, secondary farm buildings and external service expenses might need to be undertaken (Latruffe and Piet 2013). Moreover, the division of land into small farms leads to waste of corners and boundaries making it difficult to operate large machines-especially tractors. Even when land parcels are large but fragmented, moving heavy equipment from one field to another can increase costs as machines need to be dismantled and reassembled (Bentley 1987). Thirdly, land fragmentation may alter the production choices and constrain management practices. Fourthly, soil quality improvements may be reduced on a remote plot, potentially reducing farm output (Latruffe and Piet 2013). On a larger scale, fragmented landscape can make provision of irrigation and drainage schemes challenging. An owner of small parcel might not be willing to give his land for construction of canal (Bentley 1987)[10].

Land fragmentation is a challenge for timber growing activities as well. Row (1978) discusses the negative impact of small tract size on nonindustrial private forestlands. As the tract size increases, the average fixed costs of administering and moving equipment for treatment to the site decreases. The small tract sizes reduces owners incentives to undertake timber-growning investments. Also, studies have shown that an increase in holding size increases timber supply. Increased fragmentation, however, increases harvesting and transaction costs, and the differences

[10] On the other hand, fragmentation leads to an increased diversity in land quality so that the allocation of crops across plots may be optimized, potentially increasing overall yields. In addition, it may give greater opportunities for risk diversification, thereby reducing production risks at the farm level (Latruffe and Piet 2013).

in management objectives of landowners over a landscape, could adversely affect the timber supplies (Mehmood and Zhang 2001). Forest fragmentation is also a challenge for ecosystem management affecting ecosystem processes and patterns (Butler, Swenson and Alig 2004). Measures of spatial fragmentation have been used to study the impact of land use fragmentation on residential housing values. Fragmented landscape is also a challenge for residential properties. T. Kuethe (2012) found that low levels of fragmentation negatively affected the house prices, however, higher levels of fragmentation positively affected prices in Milwaukee, Wisconsin.

Besides studies on land fragmentation, a number of studies have focussed on the checkerboard landownership pattern as well. The unique nature of checkerboard landownership pattern makes it an interesting topic for policy makers, ecological sciences and economics alike. The interlocked landownership pattern presents dual challenges today: problem of private access over public land and limited public access over private lands (Powers 1982). Thus, lack of access is cited as the main motivation behind a large number of land exchanges between the forest service and private parties (Pryne 1994). Managing checkerboard lands is a challenge for the adminitrative agencies as well. As mentioned above, the responsible federal agency has to incur costs for surveying, marking and establishing boundaries (Kmon 1994)[11]. Moreover, increasingly land management involves ecosystem management which conflicts with the checkerboard landscape. Concerns about biodiversity conservation and long-term sustainability, has led to a number of studies that look at the distribution of forest resources and land uses across multiple-ownership patterns (P. G. Dodds (1986-87); Ohamann and Gregory (2002); Stanfield, Bliss and

[11] Steve Lydick, field manager at Roseburg Office, Bureau of Land Management mentioned that in recent years managing wild fires in a resource efficient way has been a major challenge in the checkerboard. Also, mentioned issues related to complex reciprocal rights of way and law enforcement costs as management challenges in the checkerboard. Conversation held via telephone on June 12th, 2014.

Spies (2002)). Freid (1994) studied the relationship between distributions of land owernship to road placement pattern in Willamatte Valley, Western Oregon. The study finds that road density was highest on large blocked up industry lands, intermediate on checkerboard lands, and lowest on federal lands (Freid 1994). Kunce, Gerking and William (2002),using checkerboard landownership pattern as a natural experiment setting, compared drilling costs on federal and private lands in the Wyoming Checkerboard[12]. Akee (2009) investigates the impact of transaction costs on housing market in southern California where Agua Caliente Tribal Nation and the Southern Pacific Railroad lands were distributed in a checkerboard manner in the late 1800s. Due to sales and leasing restrictions, very little development took place on tribal lands compared to non-inidan lands. Once the transaction costs were removed, however, there was convergence in home values and the number of homes constructed on tribal and non-indian lands (Akee 2009). All of the studies on the checkerboard lands have tried to exploit the natural experiment setting provided by these lands to compare outcomes for different landowners. To my knowledge, no study has examined checkerboard lands as a property rights system. Next, I discuss the theoretical model.

## 3.1 MODEL SETTING AND ASSUMPTIONS

I use an economic model in which a profit maximizing landowner intends to maximize the net value of her land or net profits. Initially, I assume that land sections lie in a predefined rectangular survey (RS) grid. The land is demarcated into thirty-six squares, each square covering an area of 640 acres. Each landowner owns one land section (640 acres). Each

[12] The main findings of this paper were retracted in 2007 (Gerking and Morgan 2007).

landowner has access to the same level of technology. Land quality (topography, slope, soil quality etc.) is homogenous across sections.

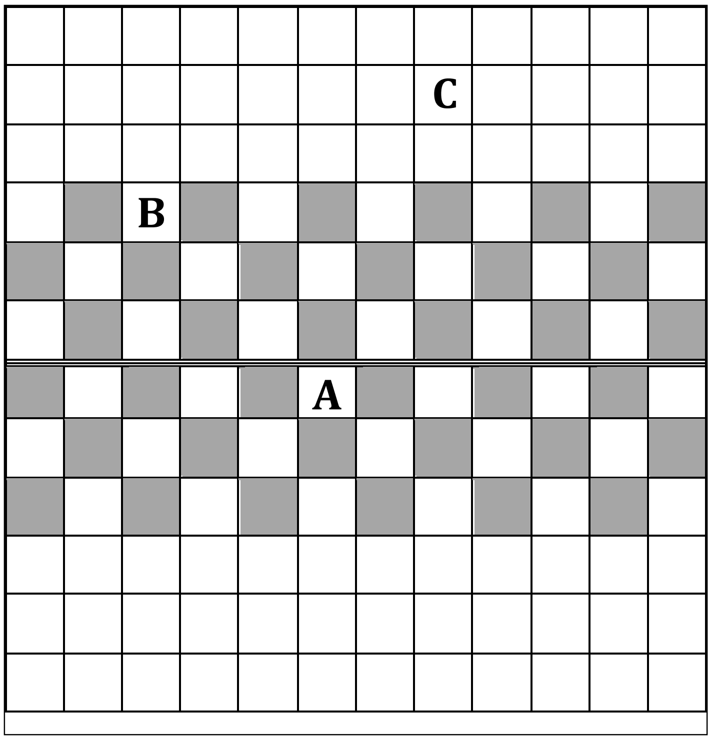



**Figure 3-1 Schematic of checkerboard and non-checkerboard lands.**

One possible scenario is depicted in Figure 3-1. This figure is a schematic showing checkerboard and consolidated private lands adjacent to each other in a 12 by 12 miles area. Each land section measures 640 acres in area. Public and private lands are shown in grey and white colors respectively. Landowners can choose optimal acreage by subdividing their square plots or purchasing neighboring square sections from the land market. Assume that the optimal land acreage is greater than 640 acres for the land use activity in this area. Therefore, landowners can attain optimal acreage by purchasing sections (or subsections) from the land market.

Furthermore, assume that public lands cannot be leased to private landowners[13]. Consider three landowners. Landowner A's section is located inside the checkerboard, surrounded by public lands. Landowner B owns a land section on the edge of the checkerboard, with public land on three sides and private land on one side. Lastly, landowner C owns a land section outside the checkerboard, surrounded by only private lands.

**The Role of Transaction Costs**

First, consider a setting in which there are no transaction costs. That is, there are no enforcement costs, no measurement costs, no fencing and infrastructure costs, and no costs for gathering information about location and shape of section for exchange. Being in a predefined rectangular survey (RS) grid, the landowner does not incur surveying and demarcation costs (Libecap and Lueck 2011). In absence of transaction costs, landowners A, B and C can choose optimal acreage by purchasing lands from neighbors. Landowner A (located inside the checkerboard) will likely negotiate with public landowners to achieve optimal land acreage, as long as the benefits of owning larger acreage outweigh the costs of the lands obtained. As suggested by Coase (1960), as long as transactions are costless, rights would always be reassigned to maximize the value of production. Therefore, optimal solution for profit maximizing landowners would be the same, irrespective of their location inside or outside the checkerboard. For given similar land characteristics and rectangular survey grid, the optimal solution for all land owners would be a set of squares (Libecap and Lueck 2011).

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[13] This assumption might not hold in the real world as private landowners might have grazing rights or rights to timber on federal land thus, land use by any single land owner might not be limited to her land sections. This assumption is made for simplicity.

Now consider the impact of transaction costs. All previous assumptions hold, except now the costs of trade, the costs of information, and the costs of coordination are involved. As mentioned in Section 2, exchanging public land is a lengthy process entailing huge transaction costs. The simplest case of coordination is when optimal size is less than 640 acres. In this situation, landowner can simply divide her land into desirable size land parcels and make optimal investment decisions. The more challenging problem is if the optimal land size is larger than the current land size. Obviously, if one landowner achieves the optimal land size the neighboring landowners have to forgo optimal land size and future earnings thus must be compensated accordingly. In order to exploit economies of scale, neighbors would have to get together and negotiate which one of them buys other land sections (or sub-sections) (Bleakley and Ferrie 2014).

Now suppose that optimal acreage for land use activity is greater than 640 acres. For simplicity, assume optimal land size is 4 sections (2,560 acres). Each landowner chooses optimal perimeter to maximize the net present value of land. Consider profit-maximizing decisions of landowner C, whose section is completely surrounded by private lands. At any point, landowner C has the option to purchase land from at least 9 neighboring landowners to achieve optimal land size. Moreover, landowner C can expand his land in horizontal, vertical, diagonal and ring direction depending on her preferences. Now consider landowner B. Landowner B is surrounded by public lands on three sides and private land on one side. Unlike landowner C, landowner B cannot purchase sections from all neighboring landowners. At best, landowner B can negotiate with 6 out of 9 neighboring section owners as rest are public sections that cannot be bought from the traditional land market. Landowner B can expand her land in a T-shape, upward vertical direction, diagonally and in a ring. Lastly, landowner A, whose land section is located inside the checkerboard surrounded by public lands on all four sides, can only purchase 4 diagonal land sections to achieve the optimal acreage. Therefore, landowner A can only expand diagonally or in a ring. Moreover, landowner A loses benefits, from owning contiguous land sections. Thus, landowner A's land loses value as she is unable to employ optimal investments for land use activity[14]. Figure 3-2 illustrates a simple situation where optimal land acreage is 4 sections (2,560 acres).

In this framework, checkerboard land ownership pattern in which alternating sections are governed by different property rules (e.g. federal lands) affects a land owner's decision to achieve optimal land shape for her particular land use activity. Individual land owners inside and outside the checkerboard act to minimze the costs of owning a given optimal land acreage. The above theoretical model suggests that for given optimal land acreage (4 sections), owning land inside the checkerboard limits the possible land shapes for land owners and generally, leads to more irregular land configurations. Irregular land shapes can lead to higher production and demarcation costs.

[14] Lands organized in irregularly shaped polygons can raise measurement, coordination, property rights enforcement, and fencing costs. Moreover, irregular land arrangements can increase costs for road construction (Libecap and Lueck 2011). Organizing lands in regular shapes is one of the motivations behind land consolidation projects as regular shapes facilitate agricultural development and appropriate land use (Demetriou, See and Stillwell 2013). Therefore, landowners are expected to create regular landholdings, whenever possible.

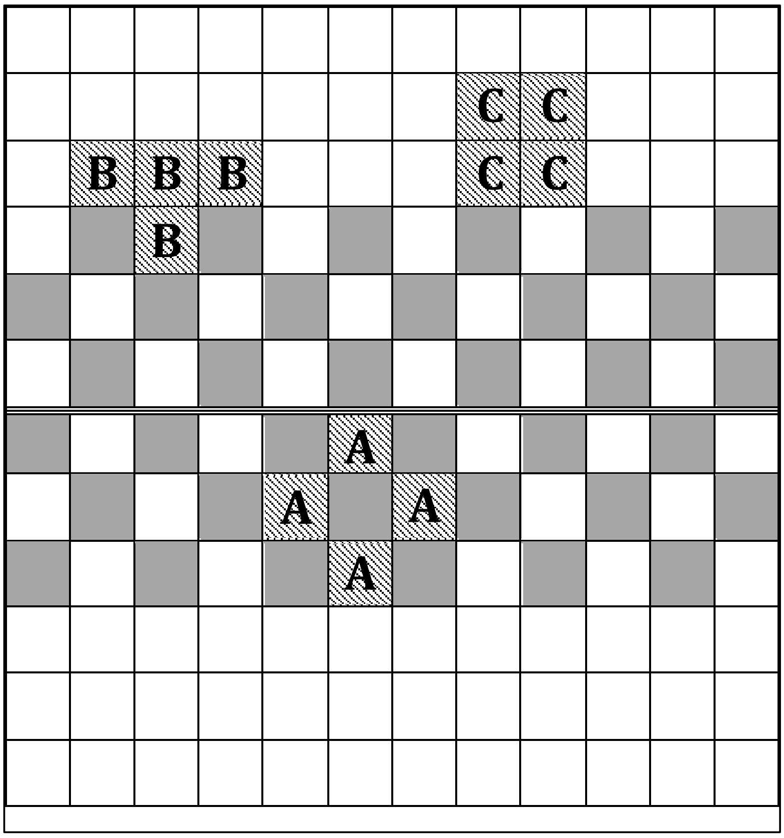


**Figure 3-2 Schematic of checkerboard and non-checkerboard lands with three possible land consolidations.**

Table 3-1 illustrates the problem further. First suppose that the optimal land size is 1 section (640 acres) then the land value for all landowners would be the same, assuming similar land characteristics, irrespective of their location inside or outside the checkerboard. Now suppose that optimal land size is 4 sections (2,560 acres). The case is illustrated in Figure 3-2. For simplicity, assume that the rent (periodic profit), benefits net of costs, generated from land $(\pi_i)$ is a function of the area $(a_i)$ and perimeter $(p_i)$ of the landholding where $i$ represents landowners A, B and C; and $t_i$ represents topography and other soil quality variables. Revenue $(r_i)$ is the benefits from production.

Now if the optimal land size is larger than 1 section then for landowners to exploit economies of scale, land parcels need to be contiguous, and an increase $a_i$ is associated with an increase in revenue $r_i$. An increase in area $(a_i)$, however, also increases the costs associated with managing larger area. Furthermore, an increase in number of boundaries increases measurement, enforcement and demarcation costs. For simplicity, assume that costs of fencing, measurement, enforcement etc. are a constant value per mile of perimeter of the property at \$10/mile. Also, assume that the additional revenue from addition of a section is constant \$50. As shown in table, as the optimal acreage gets larger than 1 section, rents (revenue less costs) generated for landowner B and C always exceed rents generated for landowner A. Thus for $j > 1, \pi_c > \pi_b > \pi_a \; where \; \pi = \sum_{j=2}^{4} \pi_j$. Moreover, the bigger is the optimal acreage, the higher is the difference in profits between landowner A and C that is, $\frac{\delta(\pi_c/\pi_a)}{\delta a} > 0$.

**Table 3-1 Difference in land value of private lands inside and outside the checkerboard.**

| Optimal Land Size | 1 Section | | | |
|---|---|---|---|---|
| **Landowner** | **Perimeter (miles)** | **Revenue (\$50/section)** | **Costs (\$10/mile)** | **Rents (\$)** |
| A | 4 | 50 | 40 | 10 |
| B | 4 | 50 | 40 | 10 |
| C | 4 | 50 | 40 | 10 |
| Optimal Land Size | 4 Sections | | | |
| A | 16 | 200 | 160 | 40 |
| B | 10 | 200 | 100 | 100 |
| C | 8 | 200 | 80 | 120 |
| Optimal Land Size | 8 Sections | | | |
| A | 22 | 400 | 220 | 180 |
| B | 14 | 400 | 140 | 260 |
| C | 12 | 400 | 120 | 280 |

Assume that revenue from each additional section is constant at \$50 and costs per mile are \$10.

## 3.2 FORMAL MODEL

The previous analysis and example are now extended into a formal model of landowner behavior. A simple way to examine the effect of checkerboard landownership pattern is to consider a case in which a landowner decides the optimal boundary of her landownership to maximize the value of her land net of costs. Consider a large tract of land demarcated in 1 by 1 mile squares and each landowner decides the boundary of her landownership for a given level of 'checkerboardedness'.

In the above setting each land owner $(i)$ minimizes costs $(C_i)$ for a given degree of 'checkerboardedness' $(CB_i)$. 'Checkerboardedness' is exogenous to the landowner and is expected to affect production and demarcation cost. Checkerboard land ownership is likely to lead to higher costs of production owing to increased travelling time between land sections, technology constraints due to fragmented property and additional investment costs in road network etc. for connecting different parts of the property. Moreover, irregular shapes entail higher costs of demarcating the land boundaries, enforcing property rights and fencing the land boundary[15] (Libecap and Lueck 2011). Costs, $C_i$, include both demarcation $(C_{dem})$ and production costs $(C_{prod})$. Essentially, then each landowner intends to minimize costs by choosing optimal perimeter for given optimal area and the amount of 'checkerboardedness' as measured by the checkerboard measure $(CB_i)$.

[15] For some land use activities, like timber harvesting, fencing might not be a real concern. For other activities, like grazing, fencing costs are more pertinent. The model is developed to include all sorts of costs that might be associated with larger perimeter for a given area. These might be one time costs but are likely to be spread over a few years.

$$\min_{p_i} C_i = C_{prod} + C_{dem} \tag{1.1}$$

$$= f(q_i, p_i(\bar{A}, CB_i), CB_i)$$

Subject to:

$\bar{A}$ is the given optimal acreage required for particular land use activity (1.2)

$$p_i \leq 4\bar{A} \tag{1.3}$$

where $CB_i$ is an exogenous variable (1.4)

Cost of ownership $(C_i)$ is a function of quantity of output produced $(q_i)$, soil quality or topographical characteristics $(t_i)$, area $(\bar{A})$, perimeter $(p_i)$ and the checkerboard measure $(CB_i)$. Checkerboard measure and soil quality characteristics are exogenous to the landowner. Further assume that quantity of output is same for all land sections and therefore exogenous to the landowner. Equation (1.3) represents area and perimeter relationship in a world of square sections. Essentially, for a given level of 'checkerboardedness' and optimal land area, each landowner chooses perimeter that minimizes the costs of ownership and therefore, maximizes rents.

Checkerboard measure $(CB_i)$ represents the degree of 'checkerboardedness' of a land section and assumes values between 0 and 1[16]. In figure 3.2, landowner A and landowner C would have a checkerboard measure of 1 $and$ 0, respectively. As $CB_i$ tends to 0 it implies that the land section is less 'checkerboarded' and the opposite holds as $CB_i$ tends to 1. A $CB_i$ value of 1 indicates that the land section is completely in a checkerboard such that each land section is surrounded by public land on all four sides.

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[16] For empirical analysis I use several measures of 'checkerboardedness' but for simplicity purposes, I assume here that there exists one checkerboard measure that captures all the various facets of checkerboard landownership pattern.

Each landowner individually solves equation (1.1) where $p$ is the choice variable. The first order conditions are:

$$\frac{\delta C_i}{\delta p_i} = \frac{\delta C_{prod}}{\delta p_i} + \frac{\delta C_{dem}}{\delta p_i} = 0 \qquad (1.5)$$

$$C_p = C_{prod_{p_i}}(CB_i) + C_{dem}(CB_i) = 0 \qquad (1.6)$$

Assuming that second-order conditions for cost minimization are met, this gives us the solution that minimizes costs for any given level of checkerboardness $CB$.

$$p^* = p(CB) \qquad (1.7)$$

Subtituting this into equation 1.1, I obtain $C^*$, the minimum cost for any given value of checkerboard index, .

$$C^* = C(q_i, p_i^*(\bar{A}, CB_i), CB_i) \qquad (1.8)$$

Due to duality, optimal costs ($C^*$) imply optimal profit ($\pi^*$). The land value per acre, defined as the net present value of rents, is derived as $V_i^* = \sum_1^t \frac{\pi_i/a_i}{(1+r)^t}$ (1.9) where $a_i$ represents the land area owned by each land owner and $r$ is the discount rate. Empirically, $V_i^*$ represents the land value per acre.

## 3.3 PREDICTIONS

In this section I present predictions derived from the above theoretical model and additional predictions. All predictions are derived for land sections as defined by the US

Rectangular Survey.

**Prediction 1a:** *Private land sections outside the checkerboard will have higher per acre land value than private land sections inside the checkerboard.*

In the above setting, lands inside the checkerboard would have higher values of the checkerboard index with $CB$ taking values closer to 1. Landowners owning lands inside the checkerboard would incur higher demarcation and production costs thus land values would be lower. Differentiating $V^*$ with respect to $CB_i$ gives the first prediction:

$$\frac{\delta V^*}{\delta CB_i} = \frac{\delta \frac{\pi_i^*}{a_i}}{\delta CB_i} = \frac{\delta R(q_i, t_i) - \delta C_I^*}{a_i \delta CB_i} = -\frac{\delta C_i}{a_i \delta CB_i} = -\frac{C_p \frac{\delta p^*}{\delta CB_i} + C_{CB_i}}{a_i} \quad (1.9)$$

From the first –order conditions, however, $C_p = 0$. Therefore, by Envelope Theorem,

$$\frac{\delta C_i}{a_i \delta CB_i} = \frac{C_{CB_i}}{a_i} \quad (1.10)$$

The sign of the derivative is positive based on the assumption that minimum costs of land ownership are positive. Then,

$$\frac{\delta V^*}{\delta CB_i} = \frac{-C_{CB_i}}{a_i} \quad (1.11)$$

As checkerboard index increases, the cost of landownership increases, assuming perimeter is held constant at optimal value. Higher costs imply lower profits and therefore, lower land value per acre.

**Prediction 1b:** *Private lands on the edge of checkerboard would have higher land values per acre compared to private lands inside the checkerboard.*

This prediction is a corollary of prediction 1a. Since the private lands on the edges of the checkerboard would share at least one boundary with private lands, the owners of these lands can attain optimal land size by purchasing neighboring sections. In some sense, the hypothesized negative effect of being in a checkerboard is less severe for these landowners.

The next set of predictions relate to landowner incentives to invest in their lands and land uses. These predictions follow largely from the literature on property rights and their effects on land uses and investments.

**Prediction 2:** *The difference in land values for land sections inside and outside the checkerboard increases if optimal land size is greater than 640 acres (1 section).*

Optimal land size varies for different land use activities. It is predicted that larger land areas are required for forest use activities compared to commerical and industrial areas. Therefore, expected negative effect of checkerboard landownership pattern is higher when the dominant land use activity in the section is forest related.

**Prediction 3:** *There will be more roads per unit of land on private lands outside the checkerboard than on private lands inside the checkerboard.*

This prediction follows from the difference in incentives and costs offered by the two land arrangements. From the theoretical model, the optimal land value $V^*$ decreases as checkerboard measure $CB_i$ increases. Lands inside the checkerboard are associated with lower land values per acre and this negatively affects the landowners' incentives to invest in land improvements. Private lands inside the checkerboard bear additional communication and negotiation costs to construct roads therefore, the road network is expected to be less dense[17].

[17] Field managers at Bureau of Land Management, Roseburg Office, Steve Lydick and Max Yager, suggested that calculating payments for road construction and who pays for what segment of the road, is a complex and cumbersome process. Conversation was held via telephone on June 12th, 2014 and June 19th, 2014 with Steve Lydick and Max Yager respectively. Meghan Tuttle, Forest Land Use Manager for Weyerhaeuser, also mentioned complex easement process as a challenge in the checkerboard. Conversation with Meghan Tuttle was held via telephone on June 18th, 2014.

# CHAPTER 4. EMPIRICAL FRAMEWORK AND ANALYSIS

In this section I use data from Douglas County in southern Oregon to test the predictions of the theoretical model. I begin in section 4.1 by describing the Douglas County study area followed by discussion of data collected for this study. Section 4.2 summarizes the ideal data needed for this study and the data actually collected. Empirical strategy and analysis is presented in section 4.3. Later I will be able to control for land and economic characteristics.

## 4.1 STUDY AREA

The empirical setting for my study is Douglas County in Oregon. Panel A in Figure 4-1 shows the railroad land grants in Oregon and Panel B illustrates the geographical location of Douglas County. The history behind creation of checkerboard pattern of land ownership in Oregon was discussed in detail in chapter 2[18]. At the time of forfeiture of the railroad land grant, about 80% of unsold grant lands (approximately 650,000 acres in Douglas County) were present in five lower counties of Oregon (Richardson 1980). Furthermore, according to Public Land Statistics (2011), Douglas County had the largest acreage (727,953 acres) of Oregon and California (O&C) lands in the state (see Appendix B for details). I chose this area because it contains a large and mostly intact checkerboard. Figure 4-2 shows the landownership pattern in Douglas County.

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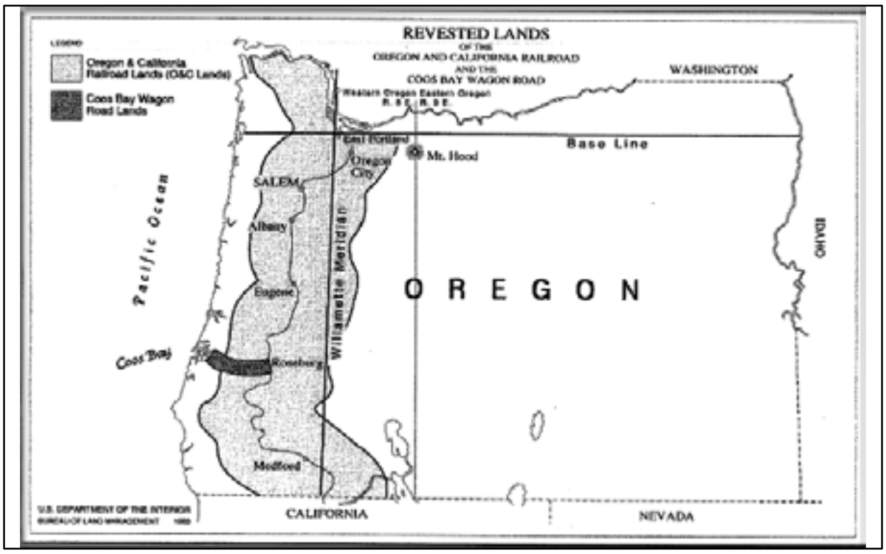
[18] The Oregon and California (O&C) Railroad Land Grant awarded odd-numbered sections to private companies while retaining even-numbered sections in public ownership in a 20-mile wide strip (primary lands) on each side of the right of way, thus creating a checkerboard landownership pattern. Furthermore, to compensate for already patented lands, railroad companies were able to select odd-numbered sections from an additional 10-mile wide belt on each side of the primary lands. Essentially, the O&C railroad land grant created a 60-wide strip of checkerboard landownership pattern.




**PANEL A- Oregon Railroad Land Grants**


**PANEL B- Douglas County, Oregon**

## Figure 4-1 Map of Oregon RR Land Grant and Oregon Counties

Source: (Oregon Geospatial Enterprise Office 2007) & Oregoncounties.org

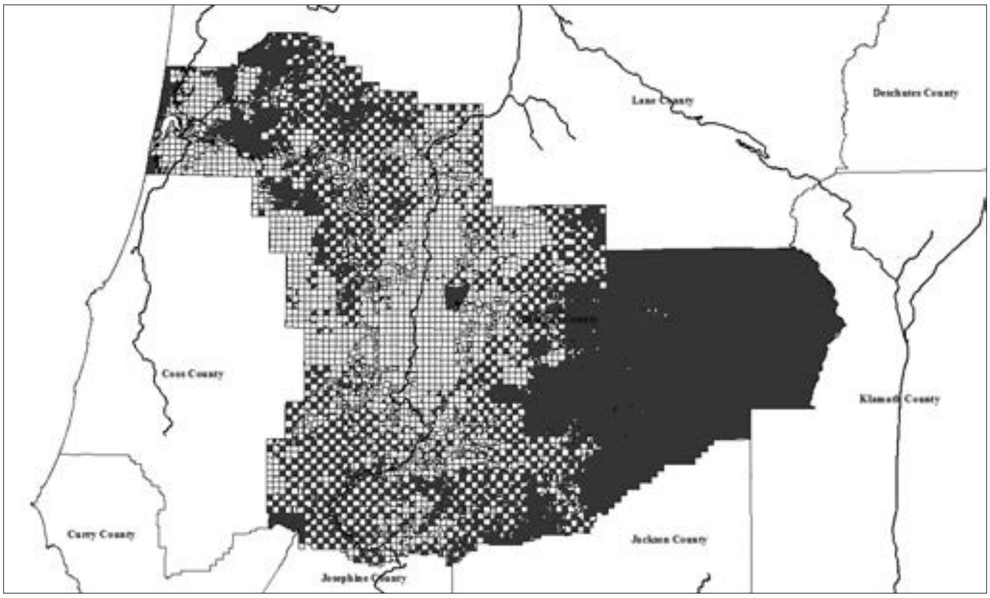



**Figure 4-2 Checkerboard Landownership in Douglas County, Oregon (2011)**
Public and private lands are represented in grey and white colors respectively. Black lines represent railroads through the area. Source: (Bureau of Land Management Oregon/Washginton Office 2014) (Oregon Department of Transportation (ODOT) 2013)

The historical events of the nineteenth century have created a landscape in which checkerboard and non-checkerboard lands lie adjacent to one another. As mentioned in chapter 3, a number of studies in ecology have studied the checkerboard lands in Oregon to compare land management practices on public and private lands. The economic value of timber, the endangered species act, conservation and management concerns makes this checkerboard interesting. This area has also been studied to manage forests in a manner that protects Northern spotted owl, listed as threatened species under the Endangered Species Act in 1990.

Located in Southwestern Oregon, Douglas County was first established in 1852. Douglas

County, covering an area of 5,071 square miles, extends from sea level at the Pacific Ocean to 9182 foot in the Cascade Mountains. According to U.S Census Bureau, the estimated county population is 106,940 for the year 2013. There are twelve cities in the county and Roseburg, with a population estimate of 21,884, is the county seat (U.S Census Bureau 2014). The principal industries include forest products, tourism, agriculture and fishing. The entire Umpqua River watershed lies in the county. Approximately, 2.8 million acres of commercial forestlands lie within the county boundaries. The Federal Government owns more than 50% of the land in Douglas County. The U.S Forest Service (USFS) and Bureau of Land Management (BLM) are responsible for management of these lands (Douglas County 2013).

Douglas County is located in the Coast Range Physiographic Province of Oregon which lies between 42.6 and 46.3$°N$ latitude and 122.6 and 124.5 $°W$ longitude. Coniferous forests growing on low-elevation, steep slopes, and high stream densities dominate the area (Spies, et al. 2007). The overall area has mild wet winters and cool dry summers, with climate varying depending on geographical proximity to the Pacific Ocean, latitude etc. Lands managed by the BLM are interspersed with private lands, and contain a mix of old and young forest. The industry forestlands are typically larger and are managed for timber production. The private lands in the area have been harvested at least once and are less than 80 years old (Ohmann and Gregory 2002).

Sections containing private lands in Douglas County in a 15-mile strip from California and Oregon Pacific Railroad are included in the study area. The study area approximately measures 79 by 30 miles. Public and private lands are represented by grey and white color respectively. Blue lines mark the 15-mile strip limit on each side of the railroad shown in black. Figures 4-3 shows the sections in the study area. There are 2421 sections in the 30-mile wide strip in Douglas County. 2,135 sections contain some amount of privately owned lands.

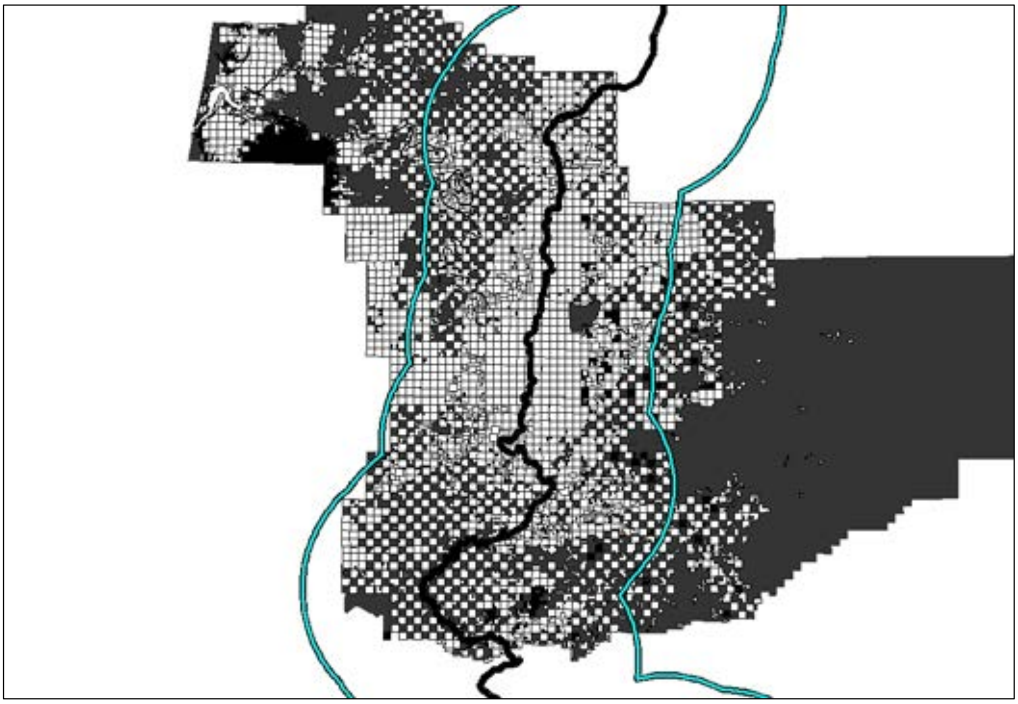


**Figure 4-3 Study Area in Douglas County Oregon**
Source: (Bureau of Land Management Oregon/Washginton Office 2014) & (Oregon Geospatial Enterprise Office 2007)

## 4.2 DESCRIPTION OF DATA

I use data from several sources to estimate the effects of checkerboard landownership pattern on land values. I divided the data into four categories. First, I discuss the land values data that comes from the Douglas County Tax Assessors Office. Second, I discuss the data I use to measure "checkerboardedness". I used Oregon land ownership status GIS data to measure the degree of 'checkerboardedness' of land sections in Douglas County Oregon (Bureau of Land Management Oregon/Washginton Office 2014). Third, I discuss data used to measure the characteristics of the land. Fourth, I discuss data used to measure economic characteristics. Table 2 presents summary statistics for the land sections used in empirical analysis.

**Land Value Data**

Following the theoretical model developed in chapter 3, to accurately test the predictions, values of 640-acres section of land are required. Land values data was obtained from Douglas County Tax Assessors Office at Roseburg for the year 2013. This data contains information at parcel level with each parcel having a unique Map Tax Lot number to identify the location of the parcel by township, range and section. For example, Map ID 23071100500 refers to township 23, range 07, section 11 and parcel number 100[19]. Using the Map Tax Lot number, I found the township, range and section for each parcel in tax assessor's data. For some parcels, Map Tax Lot number did not identify the sections, which were then identified using the legal description included in tax assessor's data. Some parcels, however, extended to more than one section so it was difficult to ascertain their true contribution to a sections' land value and thus were excluded from the analysis. The GIS data was matched with land values data resulting in sample size of 1006 sections containing privately owned lands in Douglas County, Oregon. The land value for all identified parcels inside these sections was then summed to get an estimate of the section's

[19] Map ID in Oregon comprises of Map Number information identifying township, range and section and the parcel number identifying the tax parcel. Any contiguous land area that can be described in a single description, is separately owned and conveyed is considered a parcel (Property Tax Division 2003).

land value. Similarly, the total acreage for identified parcels in a section was summed to get an estimate of the total acreage in a section. Finally, land value per acre for each section was measured as section land value/ section total acreage from Tax Assessors' data. Some sections do not exactly measure 640 acres.

For purposes of this study, the assessed "real market value" (RMV) of land, excluding value of any improvements, is used[20]. In Oregon, county tax assessors are required to estimate RMV of parcels at 100% of its market value. The RMV of land is defined as the amount in cash that an informed buyer is reasonably expected to pay an informed seller, both acting without any compulsion in arm's length transaction. This value excludes all building, structures, and improvements. A county assessor appraises the land by physical examination and a comparison of market data from similar properties. Assessors may also use rents and income to determine the RMV of certain properties. This value can change depending on market and property specific characteristics. In later years, the county assessor uses trend of similar properties to update the real market value. The value of all properties is determined as of January 1st of that year (Oregon Deparment of Revenue n.d.). The assessor estimates of RMV have been found to be quite accurate estimates of sales prices in Oregon (Hascic and Wu 2012). Grout, Jaeger and Platinga (2011) use RMV estimates to study the effct of Portland's urban growth boundary on property values. They also find that RMV values provide accurate estimates of sales price.

[20] Due to limited number of observations for sale price data, bias in sales price data, and recording errors, a number of studies instead use appraised values data prepared for property tax assessment. Although, in some cases the results might be different, the availability of appraised values data makes its use more frequent (Ma and Swinton 2012).

## Measuring the Checkerboard[21]

An important is how to measure the extent and depth of checkerboard pattern, or what can be called the, 'checkerboardedness' of a land section. Given that sections are squares, I want to differentiate a section that lies in an alternate ownership pattern with federal lands from a privately owned section in consolidated private area. To my knowledge, no such measure exists in the literature. Diversity and fragmentation indices are widely used in literature but do not serve as adequate measures of 'checkerboardedness' as they do not take into account the extent or the constraint posed by the checkerboard landownership pattern. Two very different checkerboard situations could get exactly same index value thus not identifying the unique effect of checkerboard landownership pattern (see Appendix for details on diversity and fragmentation indices). I develop five measures of 'checkerboardedness'. All these measures, however, carry potential imperfections. They do not fully capture the presence of alternate landownership around a section. Given time and data constraints, however, these measures are used for empirical analysis.

*Checkerboard Index:* Checkerboard landownership pattern refers to a land ownership arrangement in which each private land section is surrounded by public lands on all four sides and each public land section is surrounded by private lands on all four sides. The first measure used is ratio of perimeter shared with federal to total section perimeter and is referred to as the checkerboard index in rest of thesis.

[21] The word 'checkerboardedness' is used to indicate the extent of checkerboard for each section. The degree of checkerboard and 'checkerboardedness' are used interchangeably in rest of the paper. All of these measures of 'checkerboardedness' were derived from landownership status files using Arc Map 10.1. Details are discussed in Appendix A.

$$CI_i = \frac{perimeter\ shared\ with\ federal\ land}{total\ section\ perimeter} \qquad (4.2.1)$$

The index takes values between 0 and 1 where 1 indicates a perfectly checkerboarded section (the section is completely surrounded by federal land on all four sides[22]). This measure accounts for the immediate constraint on land configuration. The higher values of the index indicate that more of the perimeter of a land section is shared with federal land. This index is expected to negatively affect the land values. This index, however, does not account for the depth of the checkerboard. That is, it does not differentiate between a land section surrounded by federal land in a national forest and a land section surrounded by federal land in an otherwise mostly privately owned township.

*Sides shared:* An alternate measure of immediate constraint is number of sides shared with federal land. I included four dummy variables, one for each side of land section. Dummy variable for one side takes value 1 if only one side of the section is shared with federal land. Dummy variable for four sides takes value 1 if all four sides of the section are shared with federal land.

*Non-private lands in 3-mile and 6-mile square buffers*: I include ratio of non-private lands in a 3-mile and 6-mile square buffers to total buffer areas. That is, I measure, the ratio of non-privately owned land to total land in a 3-mile and 6-mile buffer respectively. The motivation for including these measures was to capture the landownership diversity of the

[22] This index can take all values between 0 and 1. Since in the real world, land sections are not perfect squares aligned with perfect squares, I used this index. The challenge with using only sides shared with federal land (where measure takes values 0,1,2,3,4) is that due to land arrangement sometimes half or three-fourth of side is shared so it is difficult to quantify in terms of sides.

landscape. For a land section, as the ratio approaches zero, majority of the land around that section is privately owned land. This helps in accounting for the depth of checkerboard and differentiating between a 'checkerboarded' land section inside a national forest and a 'checkerboarded' land section in an otherwise privately owned landscape. This measure, however, does not take into account the alternate ownership pattern that is characteristic of checkerboard lands. These measures also take values between 0 and 1 with 0 indicating no checkerboard.

*Ratio of land sections with high CI in a township:* Lastly, I include a ratio of number of sections with checkerboard index of greater than 0.5 in a township to total number of sections in a township containing private lands. This is included to somewhat capture the alternating landownership that is characteristic of checkerboard lands. This measure also takes values between 0 and 1 with higher values indicating more 'checkerboardedness'.

**Land Characteristic Data**

I also include a number of variables to control for land characteristics that may affect land value. To quantify land productivity characteristics, I included forestry site index and volume growth rate measures for each section. These were derived from United States Department of Agriculture soil survey. The site index ($SI$) measures the average height, in feet, that dominant and codominant trees attain in a specified number of years. The volume growth rate ($VGR$) measured in cubic feet per acre per year is the maximum wood volume growth rate expected to be produced by the important tree species (USDA National Resources Conservation

Service 2013)[23]. To quantify topography, I derived slope and elevation for each land section. These derived from Arc Map 10.1 using digital elevation model (DEM) provided by USGS (U.S. Geological Survey 1996).

## Economic Characteristics Data

Citing from the literature that suggests that land values are influenced by land use activities (T. Kuethe 2012) for each section, I determined land classification based on particular land use. I included measures to account for total acreage in a section classified as vacant forestland, farm forest, residential forest, commercial land and industrial land. For each land section, I also included number of different landowners in that section.

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[23] The site index and volume growth rate was obtained for each centroid of a section. A section, however, may contain different types of soil with varying site index and volume growth rates.

**Table 4-1: Summary Statistics**

Section Data *(N= 1006)*

| Variable Name | Definition | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| **Dependent Variables** | | | | | |
| Land Value Per Acre | Real market value of section per acre | 8421.057 | 50823.79 | 126.4938 | 1500000 |
| Density of Private Roads | Density (miles/square miles) of private roads in a section | 2.76 | 1.27 | 0 | 6.63 |
| **Checkerboard Measures** | | | | | |
| Checkerboard Index | Ratio of perimeter shared with federal land to total perimeter | .27 | .35 | 0 | 1 |
| 1 side shared | 1 section side shared with federal land | 0.08 | 0.28 | 0 | 1 |
| 2 sides shared | 2 section side shared with federal land | 0.06 | 0.24 | 0 | 1 |
| 3 sides shared | 3 section side shared with federal land | 0.06 | 0.24 | 0 | 1 |
| 4 sides shared | 4 section side shared with federal land | 0.08 | 0.27 | 0 | 1 |
| Non-Private Land in 3 miles buffer | Ratio of non-private lands in 3 by 3 square to total square area | .18 | .18 | 0 | .82 |
| Non- Private Land in 6 miles buffer | Ratio of non-private lands in 6 by 6 square to total square area | .21 | .16 | 0 | .81 |
| Ratio of High CI Sections | Ratio of sections with high CI to total sections in a township | .26 | .29 | 0 | 1 |
| **Land Characteristics** | | | | | |
| Site Index | Expected height of common tree species (feet) | 99.15 | 15.10 | 76 | 137 |
| Volume Growth Rate | Maximum wood volume growth rate (cu/ft./acre) | 133.78 | 29.27 | 86 | 214 |
| Elevation | Distance (meters) section is located above sea level | 333.61 | 179.83 | 53 | 1219 |
| Slope | The percent rise in slope | 7.22 | 4.76 | 0 | 29.08 |

**Table 4-2: Summary Statistics Continued**

| | | | | | |
|---|---|---|---|---|---|
| **Economic Characteristics** | | | | | |
| UGB Distance | Distance (miles) to nearest urban growth boundary | 4.95 | 3.90 | 0 | 17.33 |
| Railroad Distance | Distance (miles) to nearest railroad | 5.49 | 4.08 | 0 | 14.93 |
| County Seat Distance | Distance (miles) to nearest county seat | 17.87 | 7.73 | .32 | 34.86 |
| River Distance | Distance (miles) to nearest river | .53 | 0.57 | 0 | 2.60 |
| Vacant Forestland | Vacant forest land acreage (acres) | 205.28 | 236.73 | 0 | 801.96 |
| Farm Forest | Farm Forest acreage (acres) | 18.56 | 58.63 | 0 | 475.71 |
| Residential Forest | Residential Forest acreage (acres) | 1.57 | 5.29 | 0 | 69.23 |
| Commercial Land | Commercial land acreage (acres) | .02 | .24 | 0 | 4.05 |
| Industrial Land | Industrial land acreage (acres) | 1.19 | 7.63 | 0 | 118.80 |
| Land Owner Number | Number of landowners in a section | 19.54 | 50.93 | 1 | 583 |

To control for market access affects, I included market access variables derived at the section level. These variables include distance to nearest county seat, railroad, urban growth boundary and river where distance is measured as the linear distance from the center of a section to relevant features.

## 4.3 EMPRIRICAL STRATEGY AND ESTIMATION

In this section, I discuss the empirical strategy used to test the predictions laid out in chapter 3. Following the theoretical model developed in chapter 2, the hedonic pricing model is used (Rosen 1974). These models have been used to illustrate the relationship between sales prices and attributes of many goods and services, particularly land including forestland. For example, using hedonic pricing model, Turner, Newton and Dennis (1991) determined that presence of road frontage, the presence of open land, population increase, proximity to major roads and ski areas, low taxes, contributed to higher forestland prices in Vermont. Zhang, Meni and Polyakov (2013) find that road access, topopgraphy, land producticity, and population density are the main determinants of bare forestland prices in Southwest Alabama and Southeast Mississippi. Roos (1996) found that standing timber volume, land productivity and population density positively affect the forestland prices in Sweden.

A major challenge for comparing effects of different property rights regimes is to find areas where initial allocation of property rights was exogenous. As discussed in chapter 2, odd-numbered sections on both sides of the railroad were given to private companies irrespective of land quality. Therefore, quality of land was exogenous to initial property rights assignment. In order to verify the natural experiment setting for present state of Douglas County checkerboard, I compare land characteristics of private land sections outside and inside the checkerboard. For this thesis, I am using data from recent years, which is not necessarily representative of land characteristics at the time of the railroad land grants, but I am constrained by the availability of data. I conduct this comparison based on all measures of checkerboard. For each measure, I use 0.5 to divide my sample into two groups. Histograms are included in the appendix. First, I compare land quality characteristics of sections with high checkerboard index ($CI > 0.5$) to sections with low checkerboard index ($CI \leq 0.5$). Then, I compare sections completely surrounded by federal land ($4\ sides = 1$) to other sections. Next, I divide the sample into two groups based on ratio of private lands in 3-mile and 6-mile buffers. Lastly, I divide sections in the sample into two groups based on the ratio of sections in the township with checkerboard index of greater than 0.5. In table 3, high CI refers to land sections with checkerboard index of greater than 0.5 and 4 sides refer to land sections surrounded by federal land on four sides. Ratio >0.5 denotes land sections that have more than 50% non-private lands in respective buffers. Lastly, high ratio of sections with checkerboard index greater than 0.5 suggests that ratio is greater than 0.5.

Although, the results vary slightly depending on the index used, I reject the null hypothesis that the checkerboard and non-checkerboard area have the same land characteristics (e.g., site index, volume growth rate, slope and elevation) at the 5 percent level. Interestingly, a closer look at the means of high and low checkerboard groups suggests that although highly 'checkerboarded' sections are on higher elevation and have steeper-slopes, the site index and volume growth values are also higher for these lands compared to less 'checkerboarded' lands. While, land sections with high values of checkerboard measures might not be suitable for agricultural activities due to steep-slopes (Libecap and Lueck 2011), the high site-index and volume growth values suggest that these are conducive to forest related activities. Particularly, Douglas fir can grow at higher altitudes (Hermann and Lavender n.d.). More important for growth of this tree is soil quality, which as indicated by the above-mentioned indices, is conducive to growth of trees in highly checkerboarded areas. As mentioned in chapter 2, at the time of revestation of land grants, most of the unsold grant lands remaining in the area had steep-slopes and were covered with Douglas fir. Checkerboard pattern disappeared earlier closer to railroads than further away from the railroads[24]. In order to further verify the natural experiment

[24] Steve Lydick, field manager at Roseburg Office of Bureau of Land Management, confirmed that since BLM took over the management of O&C lands there have been no significant land exchanges in Douglas County. The few land exchanges, initiated by BLM for forest management and environmental concerns, have involved parcels owned by smaller owners. Moreover, he suggested that the checkerboard has not disappeared in the area as private landowners cannot match the old growth tree (trees that

setting, the sample can be limited to adjacent sections that are inside and outside the checkerboard. Based on Table 4.2 and historical maps that suggest checkerboard has not changed in the study area, the current setting is a pseudo-natural experiment setting as apparently best quality lands for forest use are stuck in a checkerboard.

Next, I examine the difference in land values between checkerboard and non-checkerboard lands. As mentioned in data descriptions, no one measure of checkerboard adequately captures the various aspects of checkerboard landownership pattern. Therefore, I use five measures of 'checkerboardedness' in this analysis. Figure 4.4 illustrates the relationship between section land values and four measures of checkerboardedness. Number of sides shared with federal land was excluded, as it is a dummy variable. As seen in the figure, all indices have a negative relationship with land values. Theoretically, each measure intends to capture a different aspect of checkerboard landscape, however, including all measures together in estimation can lead to multicollinearity**.** The correlation matrix, included in the appendix, suggests high correlation between some of these measures. A Wald test of joint significance demonstrates that these measures are jointly significant at 5% level, so these variables together contribute to explaining land values. Estimation results using all five-checkerboard measures are included in the appendix. In the following analysis, I include a mean checkerboard index, which is an arithmetic mean of checkerboard index, ratio of sections with high checkerboard index in a township and ratio of non-private lands in a 3-mile buffer. These

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have not undergone any major changes for more than 100-150 years) values that are found on BLM lands. Conversation was held via telephone on June 12th, 2014.

three measures were chosen as they have the highest correlation with the dependent variable and they capture the depth and extent of checkerboard better than other measures. A simple arithmetic mean was used, as at this stage it is not clear which index carries more weight. The following estimation results are based on mean checkerboard index, checkerboard index ($CI_i$) and ratio of private lands in 3-mile buffer.

**Table 3: Comparison of High Checkerboard and Low Checkerboard Lands in 2013**

| | Mean | | Mann-Whitney test statistic |
|---|---|---|---|
| | **Checkerboard Index** High CI (N=256) and Low CI (N=750) | | |
| Land Characteristic | **High CI** | **Low CI** | |
| Site Index | 100.13 | 98.81 | -1.16 |
| Expected Wood Volume Growth | 135.49 | 133.19 | -1.29 |
| Elevation | 468.27 | 284.35 | -16.35* |
| Slope | 9.24 | 6.73 | -7.38* |
| Land Value Per Acre | 1123.97 | 10911.79 | 16.91* |
| | **Number of Sides shared with federal land** 4 sides (N=83) and Otherwise (N=923) | | |
| Land Characteristic | **4 sides** | **Otherwise** | |
| Site Index | 99.82 | 99.09 | -1.58 |
| Expected Wood Volume Growth | 134.51 | 133.71 | -0.37 |
| Elevation | 517.76 | 315.55 | -8.31* |
| Slope | 9.05 | 7.23 | -3.02* |
| Land Value Per Acre | 636.12 | 9084.50 | 10.98* |
| | **Non- Private Lands in 3 miles** Ratio>0.5 (N=55) and Ratio≤0.5 (N=951) | | |
| Land Characteristic | **Ratio>0.5** | **Ratio≤0.5** | |
| Site Index | 102.74 | 99.04 | 2* |
| Expected Wood Volume Growth | 140.782 | 133.59 | -1.712 |
| Elevation | 519.09 | 322.86 | -6.40* |
| Slope | 8.58 | 7.14 | -2.27* |
| Land Value Per Acre | 1019.77 | 8849.10 | 6.77* |

**Table 3: Comparison of High Checkerboard and Low Checkerboard Lands in 2013 Continued**

| | **Non- Private Lands in 6 miles**<br>Ratio>0.5 (N=56) and Ratio≤0.5 (N=950) | | |
|---|---|---|---|
| Land Characteristic | **Ratio>0.5** | **Ratio≤0.5** | |
| Site Index | 104.83 | 98.92 | -2.51* |
| Expected Wood Volume Growth | 144.63 | 133.35 | -2.59* |
| Elevation | 538.64 | 321.53 | -6.98* |
| Slope | 8.01 | 7.17 | -1.89* |
| Land Value Per Acre | 998.51 | 8858.60 | 6.81* |
| | **Ratio of High CI sections in township to total private sections**<br>High (N=167) and Low (N=839) | | |
| Land Characteristic | **High** | **Low** | |
| Site Index | 98.83 | 101.35 | -1.82 |
| Expected Wood Volume Growth | 138.47 | 133.09 | -2.09* |
| Elevation | 529.14 | 294.69 | -13.25* |
| Slope | 8.94 | 6.88 | -5.56* |
| Land Value Per Acre | 963.75 | 9905.41 | 14.27* |

* Indicates significant at 5 percent level.

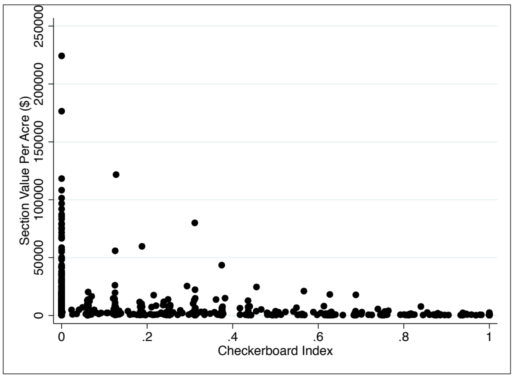


Figure 4-a Relationship between Land Value and Checkerboard Index

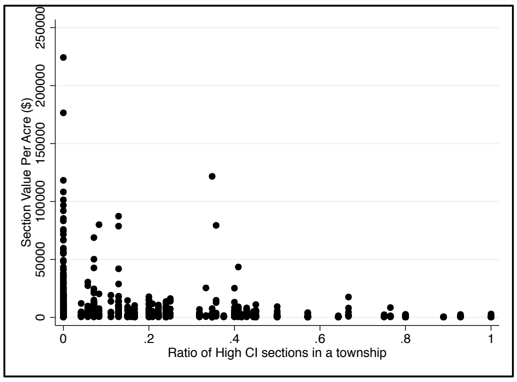


Figure 4-b Relationship between Land Value and Ratio of High CI Sections

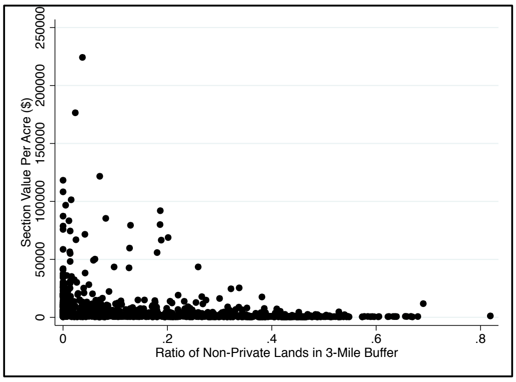


Figure 4-c Relationship between Land Value and Non-Private Lands Ratio in 3-Mile Buffer

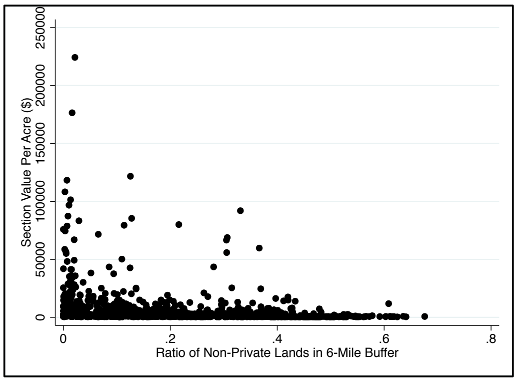


Figure 4-d Relationship between Land Value and Non-Private Lands Ratio in 6-Mile Buffer

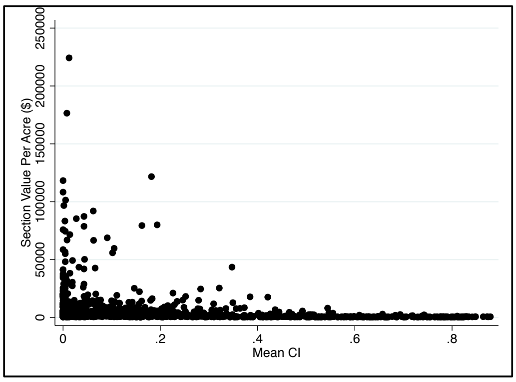


Figure 4-e Relationship between Land Value and Mean CI

**Figure 4-4 Relationship between Land Values and Measures of Checkerboard**

The scatter plots shown in figure 4.4, however, do not determine how checkerboard landownership affects land values. To be more precise, I use characteristics aggregated over section $i$ to estimate

$$lnY_i = \beta CB_i + \gamma X_i + \mu_i \qquad (4.3.1)$$

Where $Y_i$ is land value per section $(i)$. $CB_i$ represents measure of 'checkerboardedness' and $X_i$ is a vector of variables that control for land and economic characteristics of each land section. Based on theoretical model, $\beta$, coefficient for measure of checkerboardedness, is expected to carry a negative sign.

A concern when estimating hedonic price models is that data may exhibit spatial dependency relationships of two types: spatial lag relationship and spatial error relationship (T. Kuethe 2012). Particularly, when sales price of a property is affected by the sales price of neighboring properties, there is a concern that spatial lag relationship exists. A spatial error relationship is likely when the errors of the model are spatially correlated due to unobserved variables related to property location or due to the measurement errors in spatially distributed variables. For this study, my dependent variable is real market value of land that is determined by tax assessors by comparing sales of similar properties so spatial dependency is likely. Ordinary least square estimate yields biased and inconsistent estimates in presence of spatial correlation. Therefore, I also include the results of the spatial econometric specification. The spatial weights are assigned using a row-normalized spatial weights matrix. The Lagrange multiplier results suggest that both spatial lag and spatial error are statistically significant. I estimate equation 4.3.1 using both spatial lag and spatial error models. Results are included in the appendix.

To test for prediction 1 that land values inside the checkerboard are less than outside the checkerboard, I first estimate equation (4.3.1) using only the checkerboard index ($CI_i$) as the explanatory variable. The natural logarithm of per acre section value is the dependent variable. The estimates are given in Table 4.3 under column 1. The parameter estimate for the checkerboard measure has the expected negative sign. In another specification, I estimate using private lands ratio in 3- mile buffer as the explanatory variable. Next, I estimate land value on mean checkerboard index. Results are shows in column 7. All three estimates have the expected negative sign and are statistically significant[25]. These estimates support prediction 1 and imply that for any given section, as degree of 'checkerboardedness' increases, the land values decrease. Checkerboard index and mean CI are both significant and carry the expected negative sign in spatial lag and spatial error specification. Ratio of non-private lands in 3-mile buffer is significant in spatial error specification. Rest of analysis, however, is based on OLS model estimates, as the parameter estimates are very similar in magnitude.

Next, I estimate equation 4.3.1 including the controls for land and economic characteristics. The measures of 'checkerboardedness' still carry the expected sign and are significant. Among land characteristics variables, slope and elevation have the expected sign and are significant in all estimations. As the slope, measured in

[25] I have included beta coefficients and log-log model in the appendix.

percentage rise, increases the terrain becomes more rugged and hence, less suitable for agricultural activities. The estimates for vacant forestland and farm forest are both negative and significant in all the estimations. All else held constant, this indicates that land value per acre decreases as the forestland and farm forest acreage increases within a section. Moreover, the parameter estimate for residential land is significant and carries positive sign[26]. Land sections would only be divided into smaller sub-sections if the total value increases by such division (Miceli 2012). Distance to the nearest river, measured as the linear distance from center of land section to nearest river, is also significant and carries the expected sign. All else constant, as the distance to rivers increases, land values decrease. This is consistent with market access literature that suggests as distance to market increases, the costs of production increase and land values decrease. Distance to nearest urban growth boundary has the expected negative sign and is significant in two of the estimations. This indicates that as the distance to nearest urban growth boundary increases, land value per acre decreases, ceteris paribus. All four parameter estimates of market access, distance to railroad, county seat, river and urban growth boundary, carry the expected negative sign, however, only two are significant. Although, not significant, the sign of site index is counterintuitive. Site index measures the height dominant tree species will grow over a certain number of years and is used as indication of soil quality. I expected that an increase in site index would lead to higher land values. Possible explanation is that soil map units do not conform to section boundaries so selecting only soil quality measures at section

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[26] Geoghegan, Waigner and Bockstael (1997) found that people care about the landuse patterns around parcels. Not surprisingly, as the number of landowners in a section increases, the land value increases.

center does not adequately capture the quality of the entire section.[27] When evaluated at the mean values of control variables, on average, an increase in 'checkerboardedness' from 0 to 1 leads to 29 to 46 percent decrease in land values depending on the checkerboard measure used. Results are shown in table 4-3. In dollar terms, on average, an increase in checkerboard measures from 0 to 1 leads to $674 to $1034 decrease in land values. The effect of checkerboard on land value per acre is illustrated in figure 4-5.

Literature suggests that amenity value of open space affects housing markets (Anderson and West 2006). To study the effect on open space on land values, I estimate the effect of sides shared with public land on section land values, holding other things constant. Interestingly, in this study area, I do not find any positive affect of proximity to open space. All dummy variables carry the negative sign and two sides, three sides and 4 sides dummies are significant at 1% level. Therefore, compared to land sections surrounded by private lands, land sections sharing side(s) with public land have lower land values, all else held constant. Results are shown in table B-6 in the appendix.

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[27] I also collected data for productivity of forestland measured as volume of wood per acre (cu/ft./acre). This measure is strongly correlated with site index with correlation coefficient of 0.9878 therefore was excluded from analysis. Results remained unchanged when productivity measure was used in place of site index.

**Table 4-3 Parameter Estimates of OLS Estimation on Land Values**

Dependent Variable: Natural logarithm of per acre land values (N=1006)

| | | **Checkerboard Index** | | | **Ratio of Private Lands in 3 Mile Buffer** | | **Mean CI** | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Checkerboard | -2.058*** | -1.326*** | -0.289*** | -4.033*** | -2.409*** | -0.439** | -3.072*** | -2.044*** | -0.459*** |
| Measures | (0.08) | (0.09) | (0.09) | (0.19) | (0.21) | (0.22) | (0.12) | (0.14) | (0.15) |
| **Land Characteristics** | | | | | | | | | |
| Site Index | | -0.009*** | -0.001 | | -0.009*** | -0.001 | | -0.008*** | -0.001 |
| | | (0.00) | (0.00) | | (0.00) | (0.00) | | (0.00) | (0.00) |
| Slope | | -0.027*** | -0.020*** | | -0.027*** | -0.020*** | | -0.028*** | -0.020*** |
| | | (0.01) | (0.01) | | (0.01) | (0.01) | | (0.01) | (0.01) |
| Elevation | | -0.002*** | -0.001*** | | -0.002*** | -0.001*** | | -0.002*** | -0.001*** |
| | | (0.00) | (0.00) | | (0.00) | (0.00) | | (0.00) | (0.00) |
| **Economic Characteristics** | | | | | | | | | |
| Vacant | | | -0.002*** | | | -0.002*** | | | -0.002*** |
| Forestland | | | (0.00) | | | (0.00) | | | (0.00) |
| Farm Forest | | | -0.002*** | | | -0.002*** | | | -0.002*** |
| | | | (0.00) | | | (0.00) | | | (0.00) |
| Residential | | | 0.034*** | | | 0.034*** | | | 0.034*** |
| Area | | | (0.00) | | | (0.01) | | | (0.01) |
| Commercial | | | 0.113 | | | 0.118 | | | 0.110 |
| Area | | | (0.08) | | | (0.08) | | | (0.08) |
| Industrial | | | 0.006* | | | 0.005 | | | 0.006* |
| Area | | | (0.00) | | | (0.00) | | | (0.00) |
| Number of | | | 0.011*** | | | 0.011*** | | | 0.011*** |
| Landowners | | | (0.00) | | | (0.00) | | | (0.00) |
| Distance to | | | -0.018** | | | -0.017** | | | -0.015* |
| UGB | | | (0.01) | | | (0.01) | | | (0.01) |
| Distance to | | | 0.005 | | | 0.006 | | | 0.006 |
| Railroad | | | (0.01) | | | (0.01) | | | (0.01) |
| Distance to | | | -0.004 | | | -0.002 | | | -0.002 |
| County Seat | | | (0.00) | | | (0.00) | | | (0.00) |

Table 4-4 Parameter Estimates of OLS Estimation on Land Values Continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Distance to | | | -0.124* | | | -0.131*** | | | -0.130** |
| River | | | (0.05) | | | (0.05) | | | (0.05) |
| Intercept | 8.244*** | 9.973*** | 8.842*** | 8.436*** | 10.02*** | 8.833*** | 8.425*** | 9.926*** | 8.834*** |
| | (0.05) | (0.25) | (0.21) | (0.06) | (0.26) | (0.21) | (0.06) | (0.25) | (0.21) |
| Observations | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 |
| R-squared | 0.274 | 0.3739 | 0.6583 | 0.2614 | 0.3531 | 0.6569 | 0.3053 | 0.3813 | 0.6581 |
| F-stat (d.f.) | 662.10 | 221.83 | 191.50 | 428.74 | 158.67 | 186.92 | 670.69 | 214.59 | 186.80 |
| | (1004) | (1001) | (991) | (1004) | (1001) | (991) | (1004) | (1001) | (991) |

Robust Standard errors in parentheses * p<0.10, ** p<0.05, *** p<0.01

**Table 4-5 Estimated Effect of Checkerboard on Land Values Evaluated at Mean Values of Explanatory Variables ($)**

| Checkerboard Measure | Checkerboard Index | Non- Private Lands in 3- Mile Buffer | Mean CI |
|---|---|---|---|
| 0.25 | -187.26 | -283.33 | -304.61 |
| 0.5 | -361.47 | -537.21 | -576.20 |
| 0.75 | -523.53 | -764.70 | -818.35 |
| 1 | -674.30 | -968.55 | -1034.25 |

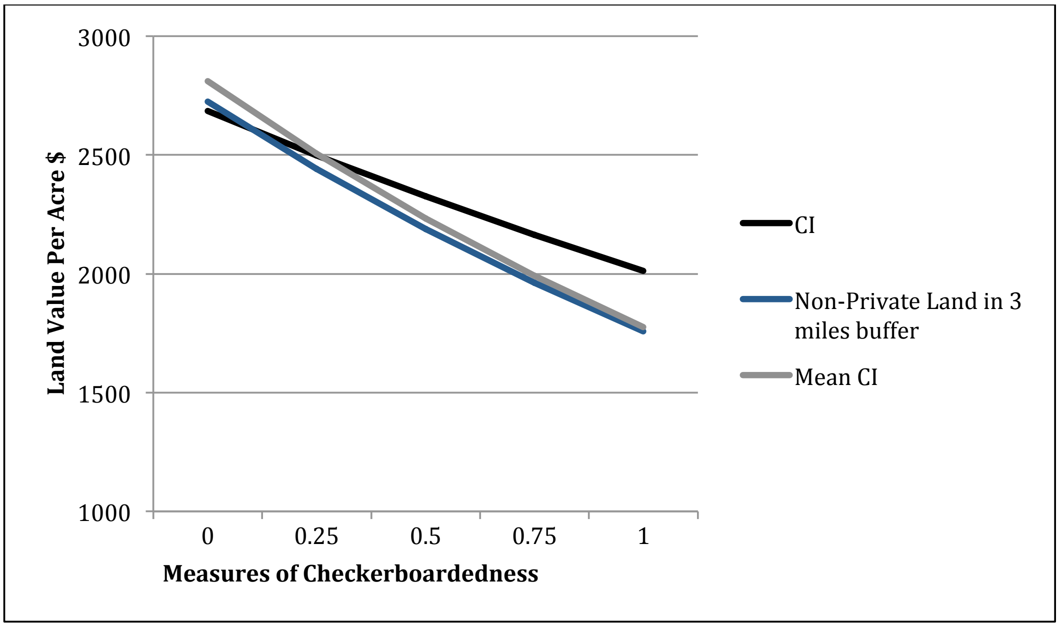


**Figure 4-5 Effect of Checkerboard on Land Value Per Acre**

To test prediction 2, I conduct separate analysis for land sections dominated by vacant forestland. The idea is that checkerboard landscape might affect land values for sections where dominant land use activity is forest related differently. As discussed in the theoretical model, optimal land size requirement varies with dominant land use activity therefore checkerboard landownership pattern might be a bigger concern for some land use activities than others. Based on review of challenges associated with checkerboard landownership pattern for forestland owners, I wanted to see if checkerboard affected forest use sections differently. As illustrated by estimation results in Table 4-4, the parameter estimate for the interaction term is positive and significant. Contrary to my hypothesis, I find that for Douglas County, the negative effect of checkerboard does not increase for forest related activity. To further understand this result, I need to look at ownership level dat

**Table 4-5 Parameter Estimates of OLS Estimation on Land Values With Interaction Term for Forest Use**

Dependent Variable: Natural logarithm of per acre land values (N=1006)

| | **Checkerboard Index** | **Non- Private Lands in 3- Mile Buffer** | **Mean CI** |
|---|---|---|---|
| CB | **-0.703*** ** | **-0.905*** ** | **-1.129*** ** |
| | **(0.17)** | **(0.33)** | **(0.25)** |
| Forest*CB | **0.001*** ** | **0.002*** ** | **0.002*** ** |
| | (0.00) | (0.00) | (0.00) |
| Site Index | -0.000 | 0.000 | -0.001 |
| | (0.00) | (0.00) | (0.00) |
| Slope | -0.018*** | -0.018*** | -0.017*** |
| | (0.01) | (0.01) | (0.01) |
| Elevation | -0.001*** | -0.001*** | -0.001*** |
| | (0.00) | (0.00) | (0.00) |
| Forestland | -0.002*** | -0.003*** | -0.003*** |
| | (0.00) | (0.00) | (0.00) |
| Farm Forest | -0.002*** | -0.002*** | -0.002*** |
| | (0.00) | (0.00) | (0.00) |
| Residential | 0.035*** | 0.035*** | 0.035*** |
| | (0.00) | (0.01) | (0.01) |
| Commercial | 0.128 | 0.130 | 0.124 |
| | (0.08) | (0.08) | (0.08) |
| Industrial | 0.005 | 0.005 | 0.005 |
| | (0.00) | (0.00) | (0.00) |
| Number of Landowners | 0.010*** | 0.010*** | 0.010*** |
| | (0.00) | (0.00) | (0.00) |
| Distance to Urban Growth Boundary | -0.021** | -0.019** | -0.019** |
| | (0.01) | (0.01) | (0.01) |
| Distance to Railroad | 0.006 | 0.007 | 0.008 |
| | (0.01) | (0.01) | (0.01) |
| Distance to County Seat | -0.003 | -0.001 | 0.001 |
| | (0.00) | (0.00) | (0.00) |
| Distance to River | -0.126** | -0.135*** | -0.138*** |
| | (0.05) | (0.05) | (0.05) |
| Intercept | 8.827*** | 8.825*** | 8.826*** |
| | (0.21) | (0.21) | (0.21) |
| Observations | 1006 | 1006 | 1006 |
| R-squared | 0.6625 | 0.6592 | 0.6633 |
| F-stat (d.f.) | 202.04 (990) | 193.63 (990) | 203.66(990) |

* p<0.10, ** p<0.05, *** p<0.01

I also explore the impact of checkerboard measures on land values by controlling for landowner specific effects. It is predicted that controlling for landowner specific effects, a landowner's lands inside the checkerboard would have lower land values than same owner's lands outside the checkerboard. I created dummy variables for all landowners in the sample who own more than 640 acres of land. Then I estimated equation 4.3.2 by including checkerboard measures and dummy variables for owners as the explanatory variables. The natural logarithm of per acre land value by owner is the dependent variable. In my sample 81 owners own more than 640 acres. Estimation results are shown in the following table 4.6. Checkerboard measures, controlling for owner specific effects, still carries the negative sign and are statistically significant.

$$lnY_i = \alpha_i + \beta CI_i + \gamma Owner_i + \mu_i \qquad (4.3.2)$$

**Table 4-6 Parameter Estimate of OLS Estimation on Owner's Land Values**

Dependent Variable: Natural logarithm of per acre land value by owner (N=644)

| | | | |
|---|---|---|---|
| Checkerboard Index | -0.675*** | | |
| | (-6.22) | | |
| Non-private lands in 3 miles buffer | | -1.249*** | |
| | | (-4.31) | |
| Mean Checkerboard Index | | | -1.001*** |
| | | | (-5.32) |
| Intercept | 10.47*** | 7.365*** | 7.350*** |
| | (30519211.92) | (8.06) | (8.11) |
| Observations | 644 | 644 | 644 |

Robust Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

**Effect of Checkerboard on Land Owner Incentives**

Next, I test prediction 3. Based on theoretical model, it is predicted that there will be more private investment on private lands per square mile outside the checkerboard than on private lands inside the checkerboard. Table 4.7a provides the difference of means test results for prediction 3. It shows that mean road density is higher on low checkerboard lands as opposed to high checkerboard lands. I estimate a simple model where I estimate determinants of road density (equation 4.3.3). As seen in the table, all measures of checkerboard have the expected negative sign and are statistically significant. Results are shown in table 4.7b. Appendix shows pictorial representation of difference in roads density.

$$lnR_i = \beta CI_i + \gamma X_i + \mu_i \qquad (4.3.3)$$

**Table 4-7a Comparison of Road Density by Checkerboard Index**

COMPARISON OF ROAD DENSITY BETWEEN HIGH CI (N=256) AND LOW CI SECTIONS (N=750)

| | Mean | S.D. | Min | Max |
|---|---|---|---|---|
| Low CI | 3.00 | 1.27 | 0 | 6.63 |
| High CI | 1.98 | 0.92 | 0.01 | 6.04 |

Mann-Whitney statistic value=9.784 (significant at 5% level)
High CI indicates land sections with checkerboard index of greater than 0.5.

**Table 4-6b Parameter Estimates of OLS Regression on Private Roads Density**

| | Checkerboard Index | Non-Private Lands in 3- Mile Buffer | Mean CI |
|---|---|---|---|
| CB | **-1.047***** | **-2.873***** | **-1.999***** |
| Site Index | 0.002 | 0.001 | 0.001 |
| Slope | 0.014* | 0.016** | 0.014* |
| Elevation | -0.001*** | -0.001** | -0.001*** |
| Forestland | 0.001*** | 0.001*** | 0.001*** |
| Farm Forest | 0.000 | 0.000 | 0.000 |
| Residential | 0.019*** | 0.019*** | 0.019*** |
| Commercial | 0.445 | 0.428 | 0.419 |
| Industrial | -0.006* | -0.008** | -0.006* |
| Number of Landowners | 0.001 | 0.001 | 0.001 |
| Distance to UGB | 0.011 | 0.022* | 0.025* |
| Distance to Railroad | -0.083*** | -0.073*** | -0.079*** |
| Distance to County Seat | -0.019** | -0.005 | -0.009 |
| Distance to River | 0.263*** | 0.228*** | 0.239*** |
| Intercept | 3.464*** | 3.330*** | 3.410*** |

* p<0.10, ** p<0.05, *** p<0.01

# CHAPTER 5. CONCLUSION

To my knowledge, this is the first economic study of the effects of checkerboard landownership pattern. In this thesis I have examined the effects of a property rights regime, checkerboard landownership pattern, on land markets in Douglas County, Oregon. I developed a theoretical model and tested a variety of hypothesis to examine the effect of checkerboard landownership on land values and incentives. The checkerboard landownership pattern is reminiscent of railroad land grants in Oregon where alternate sections of public land were awarded to private companies to facilitate the construction of the railroads. Using five different measures of 'checkerboardedness', I find that checkerboard landownership pattern leads to lower private land values and investment in land. Also, controlling for owner specific effects, the negative effect persists and is robust to use of different measures of checkerboard.

The results discussed in chapter 4 suggest that checkerboard landownership pattern increases the costs of landownership. Although, clear land titles and RS demarcation, suggest that property rights are clearly defined, the constraint imposed by checkerboard landscape increases the costs of ownership. Moreover, the rigidity of the landscape lowers incentives for landowners to invest in land improvement. To a limited extent, these findings provide an empirical justification for land consolidation demands from private landowners in checkerboard lands. The goal of this study, however, is not to propose consolidation of checkerboard lands, as there might be additional costs involved. I looked at a historical property rights assignment where land titles and demarcation system was conducive to higher land values, but constraint on land configuration acted in the opposite direction. The findings suggest that negative effects of initial misallocation of property rights can persist for a long time in presence of transaction costs and therefore, initial allocation of rights matters.

It is interesting to note that despite the demonstrated negative effect of checkerboard landownership pattern on land values, the alternating pattern of public and private lands imposed exogenously in the 1800's persists in many parts of the United States. Most checkerboards, however, have disappeared over time. As mentioned in chapter 2, I found intact and significant checkerboard landownership pattern in only five western states. It needs to be explored further why checkerboard landownership patterns persists in some areas and disappears in others. This indicates the difference in adjustments costs involved in shifting from checkerboard to non-checkerboard landownership pattern. Although, the findings from this thesis suggest that checkerboard lands are worse off compared to non-checkerboarded private lands, I do not have an estimate of adjustments costs involved and net benefits of shifting from one system to another. Moreover, it is not clear how much of theses findings can be extended to other checkerboards as for each checkerboard land characteristics and land use might vary.

Another question that requires further research is the effect of checkerboard landownership pattern on individual owners' land shapes and land acreage. Based on the theoretical model, it is expected that landowners outside the checkerboard would have larger land sizes than inside the checkerboard. Furthermore, landholdings would have more regular shapes outside the checkerboard. Due to data constraints, this analysis could not be included in this thesis.

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# APPENDIX A- Data Description

**Sample Selection**

Using the Oregon landownership status GIS data (2011) and Public Land Survey System GIS data (Bureau of Land Management Oregon/Washginton Office 2014), landownership status for each section in Douglas County, Oregon was identified. Using the 2013 railroads network GIS data (Oregon Department of Transportation (ODOT) 2013), California and Oregon Pacific Railroad (CORP)'s geographical location in Douglas County was identified. Then using ArcMap 10.1, 15-mile distance from each side of the railroad was marked. This identified a 79 by 30 mile study area containing a total of 2499 sections of which 2433 sections contain some amount of private land.

Land values data was obtained from Douglas County Tax Assessors Office at Roseburg, Oregon for year 2013. Tax assessors data contains information at parcel level with each parcel having a unique Map Tax Lot number to identify the location of the parcel by township, range and section. Using the Map Tax Lot number, I found the township, range and section for each parcel in tax assessor's data. For some parcels, Map Tax Lot number did not identify the sections, which were then identified using the legal description included in data. Some parcels, however, extend to more than one section so it was difficult to ascertain their contribution to a sections' land value and thus were excluded from the data. Lastly, the GIS data was matched with Tax Assessors data resulting in a sample size of 1006 sections containing privately owned lands in Douglas County, Oregon.

**Definition of variables**

*Land Value:* The Douglas County Tax Assessors data reports Real Market Value (RMV) for land at a parcel level. The RMV of land is defined as the amount in cash that an informed buyer is reasonably expected to pay an informed seller, each acting without compulsion in arm's length transaction. This value excludes all building, structures, improvements and timber on the lands. Township, range and section for each parcel was identified using Map Tax Lot information. Using tax exemption status information, privately owned parcels were identified. The land value for all identified parcels inside a section were then summed to get an estimate of the section land value. Similarly, the total acreage for identified parcels in a section was summed to get an estimate of the private lands total acreage in a section. Finally, land value per acre for each section was measured as section land value/ section total acreage from Tax Assessors' data.

*Measures of Checkerboard:* Checkerboard refers to a landownership pattern in which each private land section is surrounded by public land on all four sides. Five measures are included in the analysis to account for the degree of 'checkerboardness' for each section. Other measures considered to measure the depth of 'checkerboardness' are included at the end of this appendix.

*Checkerboard Index:* For each section, using ArcMap 10.1, I identified amount of perimeter shared with federal land. Checkerboard index (CI) was then calculated as

$$\mathrm{CI} = \frac{\text{Perimeter shared with federal land}}{\text{total section perimeter}}$$

*Dummy for side shared with federal land:* For each side of a section shared with federal land, dummy variable was created. Dummy variables were created for one side, two sides, three sides and four sides. Dummy variable got value 1 if entire length of the side was shared with federal land.

*Ratio of non- private lands in a 3- mile square buffer:* Using ArcMap 10.1, I converted PLSS section polygons data feature to points. Then I intersected the points data with study area to identify sections in the study area. Next, I created circular buffers measuring 1.5 mile in radius. Added field buffer area to measure area (acres) in 1.5 mile radius buffer around each section point Using minimum bounding geometry geoprocessing tool and using rectangle by width, I converted buffers into squares. Each square created has a perimeter of 12 miles thus roughly identifying 9 sections with concerned section in the middle. I measured rectangle area to measure area in 9 sections (our square). Then I clipped the square date with data identifying private lands in Oregon. This resulted in a data file that showed private area in each of the square. Then I calculate private area in each square using calculate geometry option in attribute table and created a ratio of private area in square to total area of square. The ratio non-private is simply 1- ratio of private area in a 3-mile square.

*Percentage of non- private lands in a 6-mile square buffer:* Using ArcMap 10.1, I 6-mile square buffers using the same procedure as outlines for 3-mile buffers.

**Figure A-1: Map showing buffers around sections**

*Ratio of sections with High CI in a township:* This measure was included to capture the alternate land ownership in the checkerboard. After measuring checkerboard index for each section, I found number of land sections in a township that had checkerboard index of greater than 0.5. Then, I created the index as the ratio of number of land sections with high checkerboard index to total number of privately owned sections in the study area.

*Section Area and Perimeter:* Using PLSS data for Douglas County Oregon, area and perimeter of sections were measured. For sections with many sub-sections and rivers passing through section area, Douglas County GIS data available online was used to reduce errors in measurements (Douglas County Tax Assessor 2013).

*Number of different landowners in a section:* Using the Douglas County Tax Assessors data, I identified unique landowners in a section using Owner Name. This measure also includes public owned land parcels.

*Distance to market:* Four measures of distance were included. Distance to county seat is represented by straight-line distance (miles) between centroid of a section and the nearest county seat. Locations of county seat were obtained for Oregon Spatial Data Library that provides data from a wide number of sources (Oregon State University 2008). Distance to nearest railroad (miles) was measured for each section using the railroad data obtained from Oregon Spatial Data Library (Oregon Department of Transportation (ODOT) 2013). Distance from Urban Growth Boundaries (miles) was measured for each section using the railroad data obtained from Oregon Spatial Data Library (The Oregon Department of Land Conservation and Development 2013). Distance from nearest rivers (miles) was measured for each section using the railroad data obtained from Oregon Spatial Data Library (Oregon Department of Energy 2009).

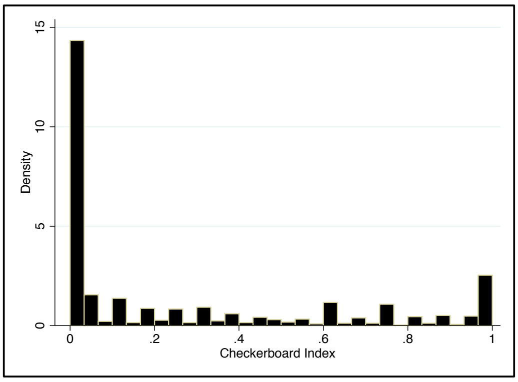
*Site Index:* Using United States Department of Agriculture (USDA) web soil survey, I created a soil quality report for Douglas County, Oregon. I matched the map units from this data with my study area. Since map units do not conform to sections, I found site index for map unit at the center of each section. The site index (SI) measures the average height, in feet, that dominant and codominant trees attain in a specified number of years (USDA National Resources Conservation Service 2013). An alternate source of data was to use forest inventory analysis data, however, this data was only available for 206 sections in the study area.

*Volume Growth Rate:* The volume growth rate ($VGR$) measured in cubic feet per acre per year is the maximum wood volume growth rate expected to be produced by the important tree species. This was also measured for the center of each section. Due to high correlation with site index, I excluded this variable from estimation analysis (USDA National Resources Conservation Service 2013)

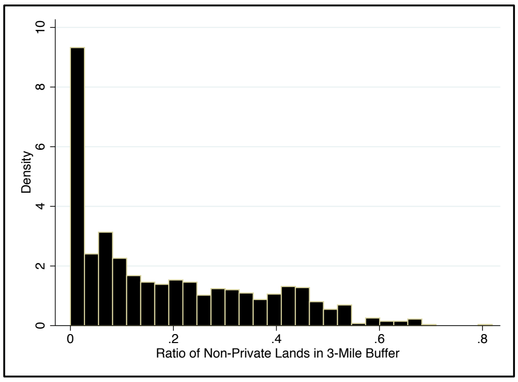
## Table A-1 Fragmentation and Diversity Indices

| Index | Formula |
|---|---|
| **Simmon's Index** | $$1-\frac{\sum a_i^2}{A^2}$$ Here $a_i$ is the area of the ith plot and A is the farm size. |
| **Januszewski's Index** | $$=\frac{\sqrt{A}}{\sum\sqrt{a_i}}$$ Here $a_i$ is the area of the ith plot and A is the farm size. |
| **Perimeter/Area Ratio** | $R=\sum P_i/A_i$<br>P= perimeter<br>A= area of interior<br>I=land cover type |
| **Distance Between Fragments** | $$edist=\frac{dh_f+\sum k\neq f\ d_{fk}}{F}$$ Where $dh_f$ is the distance from the fragment to the household and $d_{fk}$ is the distance from one parcel to another. F is the total area of the land owned by the owner (Monchuk, Deininger and Nagarajan 2010). |
| **Shape Index** | $$SI=p_i/2\sqrt{(\pi a_i)}$$ p= parcel perimeter<br>a= parcel area |
| **Fractal Dimension** | $$FD=\frac{2lnp_i}{lna_i}$$ |
| **Areal Form Factor (AFF)** | $$AFF=\frac{a_i}{p_i^2}$$ |
| **Acute Angles** (Demetriou, See and Stillwell 2013) | An acute angle is an angle that is less than 90°. Acute angles constitute a weakness for a land parcel (Amiama et al. 2008) and the more acute angles there are in a parcel shape, the worse this becomes. |
| **Reflex Angles** (Demetriou, See and Stillwell 2013) | A reflex angle is more than 180° but less than 360°. Similar to acute angles, the presence of reflex angles constitutes a drawback for land parcel exploitation. |
| **Boundary Points** (Demetriou, See and Stillwell 2013) | The number of corners of a parcel defines the density and complexity of a polygon. Thus, clearly, the desirable number of boundary points for a land parcel is four although a slightly higher number of points may not worsen a shape if all other factors are satisfied. |
| **Parcel Shape Index** (Demetriou, See and Stillwell 2013) | $$\frac{\sum P_{ij}w_j}{m}$$ Computed by multiplying the standardized score of each parameter $P_{ij}$ by the relevant paramter weight $w_j$ and summing these up divided by the number of parameters (m) involved. |

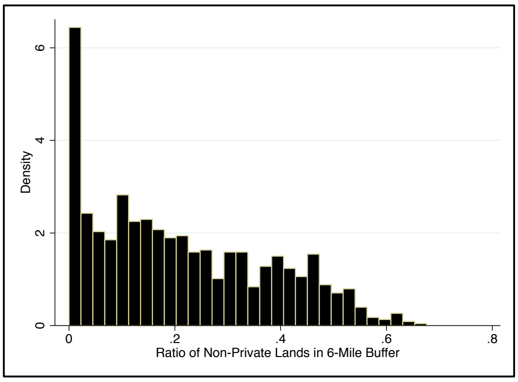
# APPENDIX B- Supplemental Results



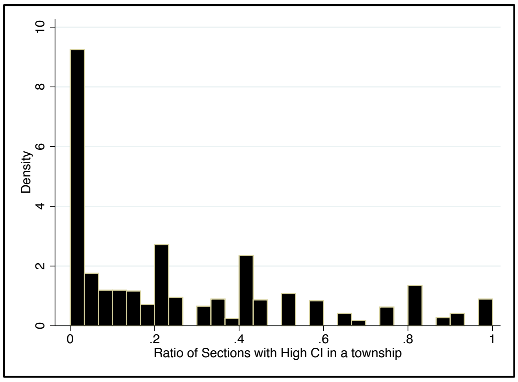

Checkerboard Index




Ratio of Non-Private Lands In 3-Mile Buffer

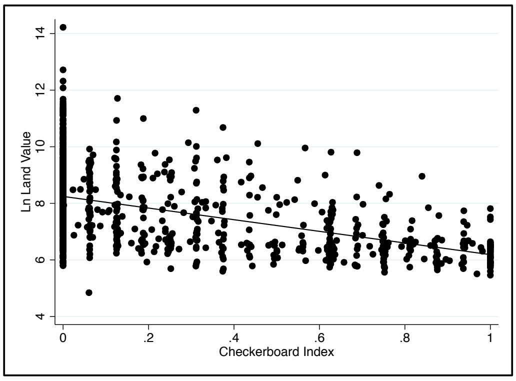



Ratio of Non-Private Lands In 3-Mile Buffer




Ratio of Section with High CI in a township

**Figure B.1 Histograms for Checkerboard Measures**



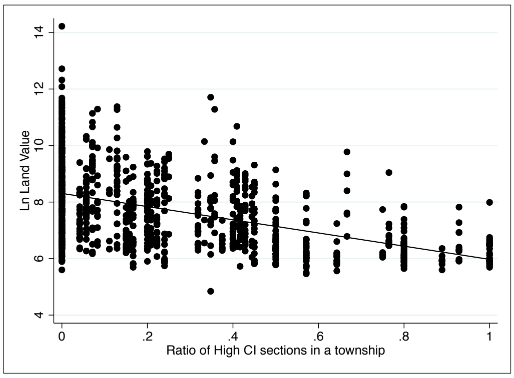
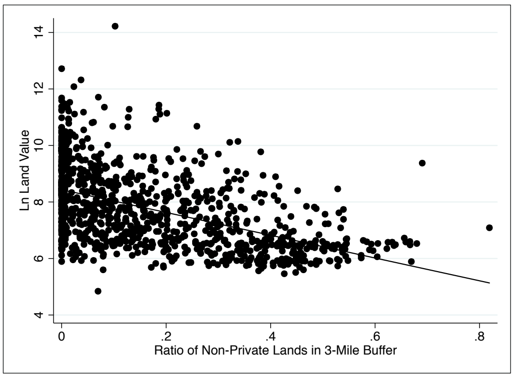




**Figure 4a Relationship between Land Value and Checkerboard Index**

**Figure 4b Relationship between Land Value and Ratio of High CI Sections**



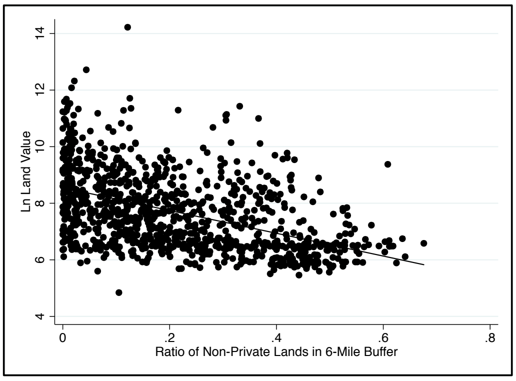




**Figure 4c Relationship between Land Value and Non-Private Lands Ratio in 3-Mile Buffer**

**Figure 4d Relationship between Land Value and Non-Private Lands Ratio in 6-Mile Buffer**

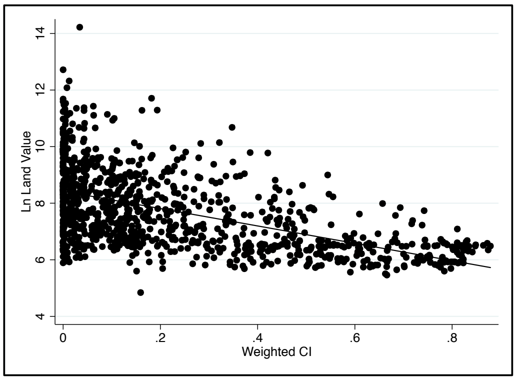



Figure 4e Relationship between Land Value and Mean CI

# Figure B.2 Relationship between Ln Land Values and Measures of Checkerboard

**Table B-1: Correlation Matrix for Measures of Checkerboard**

| | Checkerboard Index | Ratio of Sections with High CI in township | Ratio of Non-Private Lands in 3-mile buffer | Ratio of Non-Private Lands in 6-mile buffer | 4 sides |
|---|---|---|---|---|---|
| Checkerboard Index | 1 | | | | |
| Ratio of Sections with High CI in township | 0.7103 | 1 | | | |
| Ratio of Non-Private Lands in 3-mile buffer | 0.7826 | 0.8029 | 1 | | |
| Ratio of Non-Private Lands in 6-mile buffer | 0.7274 | 0.8215 | 0.9247 | 1 | |
| 4 sides | 0.5984 | 0.5055 | 0.4972 | 0.4512 | 1 |

**Table B-2 Parameter Estimates of OLS Estimation on Land Values**

Dependent Variable: Natural logarithm of per acre land values (N=1006)

| | | | | | |
|---|---|---|---|---|---|
| Checkerboard Index | -2.058*** | | | | |
| | (0.07998) | | | | |
| Ratio of Non-Private 3 Mile | | -4.033*** | | | |
| | | (0.19477) | | | |
| Ratio of Non-Private 6-Mile | | | -4.025*** | | |
| | | | (0.21924) | | |
| 1 Side | | | | -0.817*** | |
| | | | | (0.14336) | |
| 2 Side | | | | -1.465*** | |
| | | | | (0.09531) | |
| 3 side | | | | -1.708*** | |
| | | | | (0.10615) | |
| 4 Side | | | | -1.798*** | |
| | | | | (0.07168) | |
| Mean Checkerboard Index | | | | | -3.072*** |
| | | | | | (0.11861) |
| Intercept | 8.244*** | 8.436*** | 8.548*** | 8.103*** | 8.425*** |
| | (0.05171) | (0.05975) | (0.06736) | (0.04953) | (0.05651) |
| R-Squared | 0.274 | 0.2614 | 0.2297 | 0.2425 | 0.3053 |
| F-statistic (d.f.) | 662.10(1004) | 428.74 (1004) | 337.11 (1004) | 183.87(1001) | 441.18 (1004) |

Robust Standard errors in parentheses * p<0.05, ** p<0.01, *** p<0.001

**Table B-3 Estimates from Spatial Error and Spatial Lag Specifications**

| | **Spatial Lag Model** | | | **Spatial Error Model** | | |
|---|---|---|---|---|---|---|
| | Checkerboard Index | Non-Private Lands in 3-Mile Buffer | Mean CI | Checkerboard Index | Non-Private Lands in 3-Mile Buffer | Mean CI |
| CB | -0.277*** | -0.313 | -0.360** | -0.309*** | -0.572** | -0.551*** |
| Site Index | -0.002 | -0.002 | -0.002 | -0.001 | -0.001 | -0.001 |
| Slope | -0.020*** | -0.020*** | -0.020*** | -0.002*** | -0.002*** | -0.002*** |
| Elevation | -0.001*** | -0.001*** | -0.001*** | -0.002*** | -0.002*** | -0.002*** |
| Distance to UGB | 0.002 | 0.002 | 0.004 | 0.033*** | 0.033*** | 0.033*** |
| Distance to Railroad | 0 | -0.001 | 0 | 0.127 | 0.13 | 0.125 |
| Distance to County Seat | 0.008* | 0.008* | 0.009** | 0.006 | 0.005 | 0.006 |
| Distance to River | -0.137*** | -0.143*** | -0.142*** | 0.010*** | 0.010*** | 0.010*** |
| Forestland | -0.002*** | -0.002*** | -0.002*** | -0.017 | -0.015 | -0.013 |
| Farm Forest | -0.002*** | -0.002*** | -0.002*** | 0.006 | 0.007 | 0.007 |
| Residential | 0.033*** | 0.033*** | 0.033*** | -0.004 | -0.002 | -0.002 |
| Commercial | 0.121 | 0.128 | 0.121 | -0.119** | -0.126*** | -0.124*** |
| Industrial | 0.006* | 0.005 | 0.006 | -0.019*** | -0.019*** | -0.020*** |
| Number of Landowners | 0.010*** | 0.010*** | 0.010*** | -0.002*** | -0.002*** | -0.002*** |
| Intercept | 1.587** | 1.624** | 1.662** | 8.943*** | 8.942*** | 8.931*** |

* p<0.10, ** p<0.05, *** p<0.01

**Table B-4: Parameter Estimates of OLS estimation on Land Values**
All Checkerboard Measures Included

| Dependent Variable: Natural logarithm of per acre land values (N=1006) | |
|---|---|
| Checkerboard Index | -0.062 |
| | (0.16) |
| Non-Private Ratio 3 Miles | -1.037** |
| | (0.40) |
| Non-Private Ratio 6 Miles | 1.531** |
| | (0.50) |
| Ratio of High CI Sections | -0.218 |
| | (0.18) |
| 1 Side | -0.054 |
| | (0.12) |
| 2 Sides | -0.320** |
| | (0.11) |
| 3 Sides | -0.149 |
| | (0.12) |
| 4 Sides | -0.143 |
| | (0.14) |
| Site Index | -0.001 |
| | (0.00) |
| Slope | -0.019*** |
| | (0.01) |
| Elevation | -0.001*** |
| | (0.00) |
| Vacant Forestland | -0.002*** |
| | (0.00) |
| Farm Forest | -0.002*** |
| | (0.00) |
| Residential Area | 0.034*** |
| | (0.00) |
| Commercial Area | 0.130 |
| | (0.08) |
| Industrial Area | 0.006 |
| | (0.00) |
| Number of Landowners | 0.011*** |
| | (0.00) |
| Distance to UGB | -0.019* |
| | (0.01) |
| Distance to Railroad | 0.002 |
| | (0.01) |
| Distance to County Seat | -0.008 |
| | (0.01) |
| Distance to River | -0.111* |
| | (0.05) |
| Intercept | 8.873*** |
| | (0.21) |
| R-squared | 0.6634 |
| F-Stat (d.f.) | 131.44 (984) |
| Observations | 1006 |

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

**Table B-5: Beta Parameter Estimates of OLS Estimation on Land Values**

Dependent Variable: Natural logarithm of per acre land values (N=1006)

| | | | Checkerboard Index | | Ratio of Private Lands in 3 Mile Buffer | | | Mean CI | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Checkerboard Measure | -0.523*** | -0.337*** | -0.074** | -4.033*** | -0.305*** | -0.056* | -0.553*** | -0.368*** | -0.083** |
| | (-25.73) | (-14.58) | (-3.16) | (-20.71) | (-11.57) | (-2.04) | (-25.90) | (-14.78) | (-3.03) |
| Site Index | | -0.102*** | -0.010 | 8.436*** | -0.098*** | -0.009 | | -0.093*** | -0.012 |
| | | (-3.94) | (-0.45) | (141.19) | (-3.73) | (-0.39) | | (-3.57) | (-0.51) |
| Slope | | -0.093*** | -0.070*** | | -0.094*** | -0.069*** | | -0.097*** | -0.070*** |
| | | (-3.71) | (-3.85) | | (-3.71) | (-3.83) | | (-3.87) | (-3.88) |
| Elevation | | -0.312*** | -0.178*** | | -0.312*** | -0.179*** | | -0.274*** | -0.174*** |
| | | (-10.64) | (-7.85) | | (-10.64) | (-7.90) | | (-9.16) | (-7.46) |
| Vacant Forestland | | | -0.346*** | | | -0.365*** | | | -0.347*** |
| | | | (-13.55) | | | (-14.99) | | | (-14.27) |
| Farm Forest | | | -0.085*** | | | -0.084*** | | | -0.084*** |
| | | | (-6.51) | | | (-6.40) | | | (-6.42) |
| Residential Area | | | 0.131*** | | | 0.132*** | | | 0.131*** |
| | | | (6.89) | | | (6.65) | | | (6.83) |
| Commercial Area | | | 0.020 | | | 0.021 | | | 0.019 |
| | | | (1.45) | | | (1.50) | | | (1.39) |
| Industrial Area | | | 0.031 | | | 0.029 | | | 0.031 |
| | | | (1.68) | | | (1.58) | | | (1.68) |
| Number of Landowners | | | 0.387*** | | | 0.388*** | | | 0.389*** |
| | | | (9.28) | | | (9.24) | | | (9.26) |
| Distance to UGB | | | -0.051* | | | -0.049* | | | -0.043 |
| | | | (-2.15) | | | (-2.00) | | | (-1.79) |
| Distance to Railroad | | | 0.016 | | | 0.017 | | | 0.017 |
| | | | (0.71) | | | (0.75) | | | (0.77) |
| Distance to County Seat | | | -0.021 | | | -0.014 | | | -0.011 |
| | | | (-0.82) | | | (-0.53) | | | (-0.40) |
| Distance to River | | | -0.051* | | | -0.054** | | | -0.054** |
| | | | (-2.45) | | | (-2.60) | | | (-2.60) |
| Observations | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 |

t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

**Table B-6: Parameter Estimates of OLS Estimation on Land Values**

Dependent Variable: Natural logarithm of per acre land values (N=1006)

| | | Checkerboard Index | | | Ratio of Private Lands in 3 Mile Buffer | | | Mean CI | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| LN (Checkerboard Measure) | **-0.08***** | **-0.04***** | **-0.019*** | **-0.109***** | **-0.05***** | **-0.01** | **-0.12***** | **-0.06***** | **-0.015** |
| | (-15.95) | (-9.21) | (-2.10) | (-11.57) | (-6.45) | (-1.31) | (-10.21) | (-6.43) | (-1.69) |
| Site Index | | -0.01*** | -0.000 | | -0.01*** | -0.00 | | -0.01*** | -0.00 |
| | | (-4.25) | (-0.32) | | (-4.21) | (-0.31) | | (-4.55) | (-0.38) |
| Slope | | -0.03*** | -0.02*** | | -0.03*** | -0.02*** | | -0.03*** | -0.02*** |
| | | (-3.53) | (-3.77) | | (-3.69) | (-3.75) | | (-3.73) | (-3.76) |
| Elevation | | -0.00** | -0.00*** | | -0.00*** | -0.00*** | | -0.00*** | -0.00*** |
| | | (-13.00) | (-8.34) | | (-14.93) | (-8.52) | | (-15.13) | (-8.55) |
| Vacant Forestland | | | -0.00*** | | | -0.00*** | | | -0.00*** |
| | | | (-14.96) | | | (-16.23) | | | (-16.11) |
| Farm Forest | | | -0.00*** | | | -0.00*** | | | -0.00*** |
| | | | (-6.42) | | | (-6.00) | | | (-6.08) |
| Residential Area | | 0.03*** | | | | 0.03*** | | | 0.03*** |
| | | | (6.77) | | | (6.61) | | | (6.53) |
| Commercial Area | | 0.12 | | | | 0.13 | | | 0.13 |
| | | | (1.52) | | | (1.67) | | | (1.60) |
| Industrial Area | | 0.01 | | | | 0.01 | | | 0.01 |
| | | | (1.67) | | | (1.58) | | | (1.72) |
| Number of Landowners | | 0.01*** | | | | 0.01*** | | | 0.01*** |
| | | | (9.21) | | | (9.27) | | | (9.29) |
| Distance to UGB | | -0.02* | | | | -0.02* | | | -0.02* |
| | | | (-2.30) | | | (-2.24) | | | (-2.26) |
| Distance to Railroad | | 0.01 | | | | 0.00 | | | 0.0 |
| | | | (0.61) | | | (0.54) | | | (0.51) |
| Distance to County Seat | | -0.00 | | | | -0.00 | | | -0.00 |
| | | | (-0.87) | | | (-0.59) | | | (-0.53) |
| Distance to River | | -0.13* | | | | -0.13* | | | -0.13** |
| | | | (-2.53) | | | (-2.55) | | | (-2.58) |
| Intercept | 7.026*** | 9.451*** | 8.716*** | 7.283*** | 9.775*** | 8.759*** | 7.306*** | 9.850*** | 8.754*** |
| | (138.38) | (34.40) | (41.16) | (143.38) | (35.01) | (40.44) | (147.16) | (36.32) | (42.03) |
| Observations | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 | 1006 |
| R-squared | 0.2003 | 0.3459 | 0.6573 | 0.1281 | 0.3217 | 0.6564 | 0.1236 | 0.3253 | 0.6571 |
| F-statistic (d.f.) | 254.44 | | 189.21 | 133.93 | 143.29 | 187.31 | 104.34 | 140.27 | 189.74 |
| | (1004) | 161.02(1001) | (991) | (1004) | (1001) | (991) | (1004) | (1001) | (991) |

t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

**Table B-7: Parameter estimates of OLS estimation on land values**

Checkerboard Measure: Number of Sides shared with Federal Land

| Dependent Variable: Natural logarithm of per acre land values (N=1006) | | |
|---|---|---|
| 1 Side | -0.809*** | -0.070 |
| | (0.14) | (0.11) |
| 2 Sides | -1.457*** | -0.358*** |
| | (0.10) | (0.09) |
| 3 Sides | -1.700*** | -0.243*** |
| | (0.11) | (0.09) |
| 4 Sides | -1.811*** | -0.256*** |
| | (0.07) | (0.08) |
| **Land Characteristics** | | |
| Site Index | | -0.001 |
| | | (0.00) |
| Slope | | -0.020*** |
| | | (0.01) |
| Elevation | | -0.001*** |
| | | (0.00) |
| **Economic Characteristics** | | |
| Vacant Forestland | | -0.002*** |
| | | (0.00) |
| Farm Forest | | -0.002*** |
| | | (0.00) |
| Residential Area | | 0.035*** |
| | | (0.00) |
| Commercial Area | | 0.114 |
| | | (0.08) |
| Industrial Area | | 0.006 |
| | | (0.00) |
| Number of Landowners | | 0.011*** |
| | | (0.00) |
| Distance to UGB | | -0.017** |
| | | (0.01) |
| Distance to Railroad | | 0.004 |
| | | (0.01) |
| Distance to County Seat | | -0.004 |
| | | (0.00) |
| Distance to River | | -0.129** |
| | | (0.05) |
| Intercept | 8.095*** | 8.859*** |
| | (0.05) | (0.21) |
| R-squared | 0.2387 | 0.66 |
| F-Stat (d.f.) | 184.38(1001) | 161.26 (988) |
| Observations | 1006 | 1006 |

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

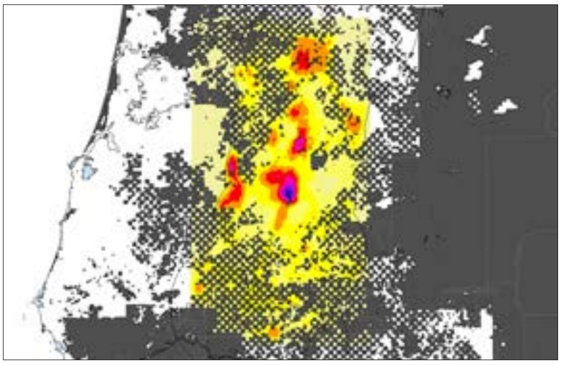


**Figure B.3 Private Road Density Map with Landownership Status**
Red color shows high density (miles/square miles) of private roads. Yellow color shows indicates low density of private roads. As seen in the figure, road density is higher on non-checkerboard lands and lower on checkerboard lands.

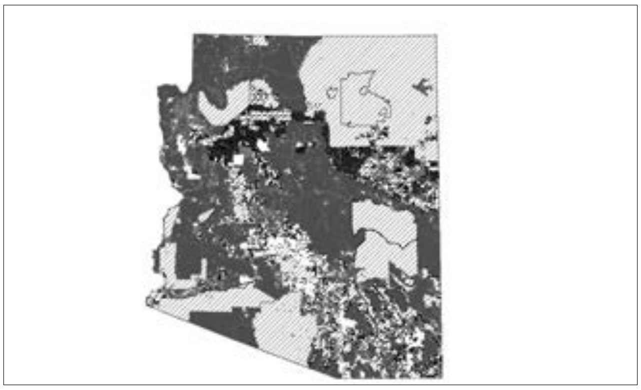


**Figure B.4 Landownership Status Map of Arizona**
Public and private lands are represented by grey and white colors respectively. Hatched lines represent all other lands in the state. ( Bureau of Land Management Arizona State Office 2012)

**Figure B.5 Landownership Status Map of Nevada**
Public and private lands are represented by grey and white colors respectively. Hatched lines represent all other lands in the state. (Bureau of Land Management Nevada State Office 2010)

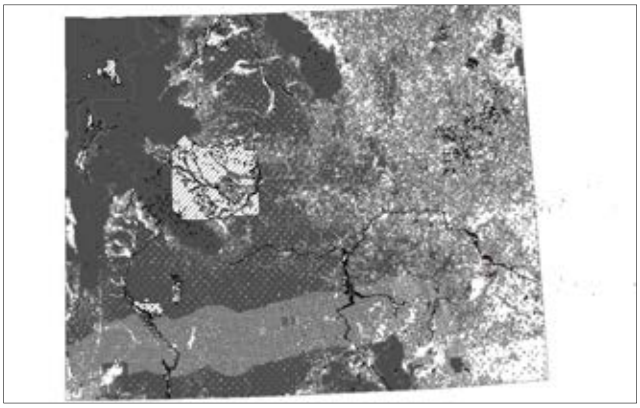


**Figure B.6 Landownership Status Map for Wyoming**
Public and private lands are shown in grey and white respectively. Source: (Bureau of Land Management Wyoming State Office 2013)

**Table B-8 Area of O&C Revested Lands, fiscal year 2011**

**Table 1-5. AREA OF OREGON AND CALIFORNIA (O&C) REVESTED LANDS, FISCAL YEAR 2011**

| Oregon County | O&C Lands /a/ | Converted O&C lands /b/ | Special Act O&C Lands /c/ | Coos Bay Lands /d/ | Total |
|---|---|---|---|---|---|
| | *Acres* | *Acres* | *Acres* | *Acres* | *Acres* |
| Benton | 51,439 | 0 | 1,720 | 0 | 53,159 |
| Clackamas | 52,448 | 35,949 | 5,688 | 0 | 94,085 |
| Columbia | 10,960 | 0 | 0 | 0 | 10,960 |
| Coos | 99,038 | 23,002 | 0 | 59,914 | 181,954 |
| Curry | 36,681 | 56,735 | 0 | 0 | 93,416 |
| Douglas | 617,679 | 95,641 | 0 | 14,633 | 727,953 |
| Jackson | 389,564 | 25,332 | 20,971 | 0 | 435,867 |
| Josephine | 259,120 | 109,244 | 182 | 0 | 368,546 |
| Klamath | 46,199 | 20,962 | 0 | 0 | 67,161 |
| Lane /e/ | 279,554 | 95,293 | 0 | 0 | 374,847 |
| Lincoln | 8,773 | 0 | 0 | 0 | 8,773 |
| Linn | 85,265 | 520 | 0 | 0 | 85,785 |
| Marion | 20,707 | 0 | 0 | 0 | 20,707 |
| Multnomah | 4,208 | 0 | 0 | 0 | 4,208 |
| Polk | 40,491 | 0 | 1,160 | 0 | 41,651 |
| Tillamook | 38,307 | 0 | 0 | 0 | 38,307 |
| Washington | 11,380 | 0 | 0 | 0 | 11,380 |
| Yamhill | 33,003 | 0 | 0 | 0 | 33,003 |
| **Total** | **2,084,816** | **462,678** | **29,721** | **74,547** | **2,651,762** |

[28]Source: (Bureau of Land Management 2011)

[28] /a/ these lands are administered by the Bureau of Land Management. .
/b/ Under the provisions of the Controverted Lands Act of June 24, 1954 (68 Stat. 271), these lands were declared to be revested O&C railroad grant lands.
/c/ Certain O&C areas were set aside by various acts of Congress to be administered by the Forest Service without losing their O&C identity.
/d/ Administered by the Bureau of Land Management; excludes Coos Bay Wagon Road timber on 87 acres of non-Federal land in Coos County.
/e/ Lane County O&C lands are reduced by 2 acres, owing to a direct land sale to resolve an unintentional occupancy trespass.
Source: (Bureau of Land Management 2011)

**Figure B.7 Western Oregon Landownership Status Map (1953)**
Source: Department of Geography, University of Oregon.

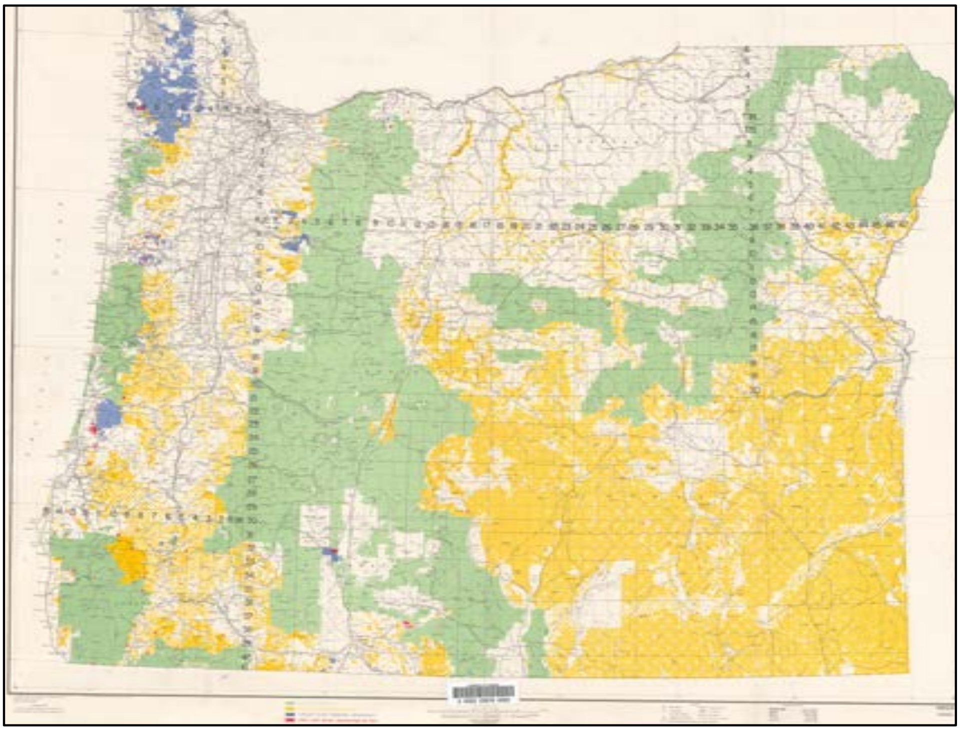


**Figure B.8 Oregon Landownership Status Map (1966)**
Public and private lands are shown in yellow and white respectively.
Source: University of Oregon Library.