THE ECONOMIC STRUCTURE OF PROPERTY RIGHTS IN NATURAL ICE

By

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Abstract:

The natural ice industry was of great economic importance at the turn of the twentieth century. Millions of tons of ice were harvested annually from lakes and rivers across the northern United States, and individuals thus found it necessary to create property rights institutions to allocate this valuable resource. This thesis examines the economic structure of property rights in natural ice as an economic choice dependent upon economic variables, including but not limited to resource value, enforcement costs, and contracting costs. It begins by examining the history of natural ice harvesting from prehistory to the present, and existing literature on the evolution of property rights. An economic model of property rights in natural ice is then developed, and predictions are made about when and where we should expect private property to natural ice to emerge. Through data collected from court opinions dating from the 1870s through 1915 an empirical test of the predictions is done which finds that the ice on non-navigable and artificial bodies of water was significantly more likely to be governed allocated through private property rights than ice on navigable and natural bodies of water.

Keywords: Property rights, natural ice, Demsetz, ice harvesting, open access, private property

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> *…the business of gathering ice for merchantable purposes has assumed extraordinary importance on our rivers. Large amounts of capital are invested. Thousands of men and of teams are employed at a season of the year when other employment cannot be obtained by them….A crop of immense value is annually produced from an exhaustless soil without sowing. The shipping business is materially aided by it. The wealth of the state is greatly increased by it.* (*Woodman v. Pitman*, 79 Me. 456, 10 A. 321 (1887))

> *The owners of a mill pond own the ice formed upon it. The owner of the bed of a stream owns the ice within it…The state owns the Hudson river in trust for the public. Apart from the statute about to be considered, the ice formed upon it, like the fish within it, becomes the property of the captor who first peacefully seizes it. Chapter 388, Laws 1879, provides that "the owners or occupants of lands and ice houses" on the Hudson River have the exclusive right of gathering ice formed on the river adjacent to the lands and ice houses so owned or occupied by them, after certain acts of appropriation are performed, such as staking out the ice field to be harvested. (Slingerland v. International Contracting Co.,* 43 A.D. 215, 60 N.Y.S. 12 (1899))

I. Introduction

For a period of U.S. history stretching from the mid 1800s through the 1920s, natural ice harvesting—now virtually unheard of—was a massive and important industry in the United

States. Revenues were in the millions, as were the tonnages of ice harvested annually. Hundreds of icehouses were erected up and down large and small waterways, their architects following detailed blueprints and instructions that could be found in publications like *The Ice Trade Journal*, which was published several times yearly and devoted itself to cataloguing the trade from the 1870s through the early 1900s. With the development of large scale ice harvesting, perishable goods could be shipped over much longer distances, and interstate trade—and even international trade—burgeoned. In tandem with the development of the industry, so too did entire systems of property rights to ice develop, in law and custom.

In this thesis I examine property rights to natural ice as an economic choice dependent upon economic variables. In the first section I examine the history of natural ice harvesting and refrigeration, from prehistory to the present. In the next section, existing literature on the evolution of property rights is examined, with particular attention paid to Demsetz (1967). Next, I develop an economic model of property rights in natural ice, and derive predictions about the affects of resource characteristics on choice of property regimes. Finally, I examine historical data on litigation in ice property to empirically test these predictions. The final section summarizes my research findings and offers conclusions.

This examination of the evolution of property rights in natural ice adds research to the dialogue on the relationship between economic growth, natural resource, use and property institutions. The study of property rights in general illuminates the role of property institutions in economic growth. Property rights establish expectations that are the foundation necessary in order for individuals to put resources to valuable use. Private property rights provide individuals with a degree of certainty that an investment in a particular resource will yield benefits above cost, and thus they establish an incentive to develop resources to produce value for the individual, and consequently for the entire system.

Second, property rights to natural resources are an area of particular interest, because the characteristics of natural resources present unique obstacles to establishing property rights over them. Unlike man-made goods and services, natural resources are not typically conveniently divided into units over which it is easy to establish private property. This is especially true of fugitive natural resources such as oil, gas, groundwater, and wildlife. Oil and gas, for example, exist in subterranean deposits from which differing amounts of the resources can be harvested depending upon the pattern and speed of harvest, both of which in turn depend very strongly on the structure of property rights to the resource. Thus property rights play a critical role in determining not just *who* harvests resources, but *how* they are harvested, and thus *how much* and *for how long* those resources will be available.

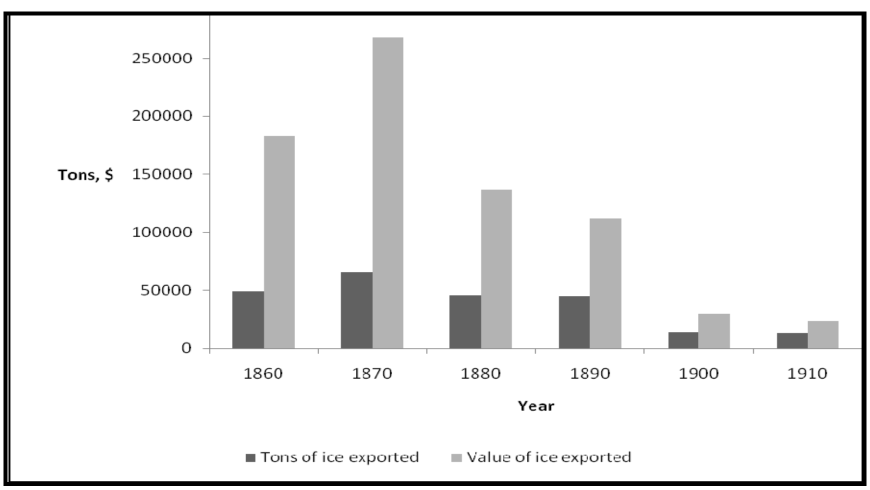
Third, examining the economic evolution of property rights allows us to observe the process by which property systems develop, rather than taking their existence as a given. This has led to a better understanding of the forces that drive the creation of and changes in property rights institutions. However, while the work of Demsetz (1967) and others allows many general inferences to be made based on theoretical models, little detailed data on the topic exists. By conducting empirical studies that examine the economic structure and evolution of property rights in natural resources, we can build knowledge about the particular implications that property rights institutions have on natural resource use.

II. The History of Natural Ice

Man’s use of natural ice for cooling dates as far back as 2,000 BC in Mesopotamia, where the first evidence of icehouses was found (Powell 2005), and 1,000 BC in China (Anderson 1953). In ancient Greece and Rome snow brought down the Alps and stored in pits was used for cooling drinks in the summer months (Anderson 1953, Cummings 1949). On India’s Hooghly plain, water in clay pots placed in reed-lined pits overnight formed sufficient ice on its surface to sell in Calcutta (Cummings 1949). In Peru, snow and ice were carried down from the Andes on donkeys to the warmer coastal climates in Lima (Weightman 2001). By the Renaissance, Parisian aristocrats were indulging in the luxury of ice cream, a delicacy that originated with the Arabs (Powell 2005). In 17th century Spain, snow used for cooling drinks—a luxury introduced by the Romans—was hauled from the Pyrennees (Thévenot 1979). France had an organized ice trade in the same era, with natural ice harvested from lakes and glaciers (Thévenot 1979). In the mid-19th century, natural ice from Norway supplied Great Britain, Germany and France (Thévenot 1979), while additional ice for Europe was harvested from glaciers in France, Italy, Switzerland, Austria and Serbia (Thévenot 1979).

The demand for ice in the United States resulted partially from entrepreneurship and partially from America’s geographic and industrial characteristics. Early efforts by Frederick Tudor and his associates brought about great improvements in harvesting and storage technology, which brought down the price of ice, popularizing its use among a greater portion of the population. While before 1830, ice in the United States was primarily used for cold drinks, Anderson (1953) notes that “…the demand for ice for these purposes alone could never have been large, but these early uses were significant in that to provide for them the first steps were taken in the development of methods of harvesting and storing natural ice.” The portion of demand not accounted for by household use followed as a natural consequence of America's large size and nascent brewing and meat packing industries. Anderson (1953) states: "The Americans, spurred by the demands of climate, the vast distances between centers of production and consumption, and the requirements of industry, have held a position of world leadership [in refrigeration]."

In the United States, a large portion of the natural ice harvested commercially originated in New York's Hudson River and in Maine on the Penobscot and Kennebec rivers. (Thévenot 1979). Smaller portions of America's ice supply were harvested from lakes, ponds, and other waterways across the northeast and Midwest, including the Illinois, Detroit, and Milwaukee rivers, and Wenham Lake. From 1865 over one million tons of natural ice were harvested yearly in Maine, which had a "dependable supply of good, thick ice." (Anderson 1953). In the warmest years, when ice supplies on the Hudson and in Maine ran short, ice was imported from Canada, and as far as Norway (Anderson 1953). In the west San Francisco received ice shipments first from Alaska, then harvested from the Sierra Nevada when freight rates decreased in the 1870s and transport by rail became practical (Thévenot 1979, Anderson 1953).



Data from Cummings (1949)

Figure 1: VOLUME AND VALUE OF UNITED STATES ICE EXPORTS, 1860-1910

Table 2: TIMELINE OF KEY HISTORICAL EVENTS OF NATURAL ICE

1806	130 tons of natural ice shipped from Boston to Martinique by Frederic Tudor, beginning the United States' international ice trade, later expanding to Calcutta in 1833, Rio de Janeiro in 1834, and Great Britain in 1840
1825	Nathaniel Wyeth invents his ice cutter, capable of producing uniform blocks of ice and significantly reducing harvest costs
1850	Cleveland, Ohio: The first commercial ice factory is erected, and produces 900 kg/day
1880	Two largest ice companies founded: Knickerbocker Ice Co. (Philadelphia) and Consolidated Ice Co. (New York)
1886	Knickerbocker and Consolidated combined sell 4 Mt of natural ice per year
1869-1899	The construction and use of ice factories for the manufacture of ice expands rapidly in the South: 5 factories in 1869, 29 in 1879, 170 in 1889
1872	United States exports 225,000 tons of natural ice, a historical maximum
1879-1915	Ice factories expand throughout the country: 39 in 1879, 220 in 1888, 790 in 1899, 2000 in 1909, 5000 in 1915
1879	New York law: "the "owners or occupants of lands and ice houses" on the Hudson river have the exclusive right of gathering ice formed on the river adjacent to the lands and ice houses so owned or occupied by them, after certain acts of appropriation are performed, such as staking out the ice field to be harvested" (Chapter 388 Laws 1879)
1895	New York law amended to include lessee of the owner (Chapter 953 Laws 1895)
1899	Maximum natural ice harvest in United States (25 Mt/year)
1926-1931	Maximum ice manufacture in the United states (55 Mt/year)

Sources: Weightman (2001), Thévenot (1979)

Property regimes in natural ice

A study of the parameters affecting property rights decisions must include an analysis of the property regimes themselves, as property rights have different characteristics across space, time, and resources. In this study, property rights regimes are divided into two categories: private property and open access. Under the former, ice harvesters have ownership of the resource from year to year, and are not required to take action to claim their ice field each season. This includes situations where ice rights are leased for a single year, as this leasing implies that someone, even if it is not the harvester, owns the resource stock, choosing variably to lease rights to its harvest. Under an open access regime, with each new season would-be harvesters must take action to claim an ice field, actions that range from staking off an area for eventual harvest to actually removing the ice.

In choosing a property regime, the costs and benefits of harvesting at a particular location were taken into account. While there are a great many aspects of the physical environment of a location that influenced its value for ice harvesting, among the most important are the quantity of ice per acre, the quality of that ice, transportation and wage aspects of location (proximity to population centers), and transport costs. The surface area of a body of water was not the only consideration in estimating the amount of ice that could be harvested there. Clearly, temperatures played a critical role, as they determined how thick ice would grow before beginning to melt again. Second, ice quality was also an important factor influencing the value of ice. Ice forming over quickly moving waters was clearer, as the motion of the water reduced the entrapment of air bubbles in the freezing process. Pollution of ice sources also decreased ice quality, especially on the Hudson River as New York City grew in population. Third, location played a role in ice value, as ice close to population centers was cheaper to transport to market, and cheaper to harvest with a larger labor supply. Finally, since the rail infrastructure in the late 1800s was still developing, ice on ponds that were far enough from rivers to require rail transport was frequently much more expensive to transport to market, as there was frequently just one rail provider, and transport by water was the much cheaper transport alternative. All of these parameters affected the value of natural ice at a particular location, but to end the list here would leave it incomplete.

A second category of costs potentially affecting the selection of property rights regimes were those related to enforcement of property rights and contracting costs. Harvesters on rivers faced risks that ice could drift downstream. Ice on a waterway above a dam could be destroyed if the water level behind the dam was allowed to drop. This was not a concern on small lakes and millponds where the owner of the land generally owned ice and control of the dam. Additionally, the number of adjacent landowners had an effect on the enforcement costs on a particular body of water. More adjacent landowners meant the work of enforcing property rights could be divided up amongst more enforcers. Finally, on artificial bodies of water, enforcement costs were likely to be lower. In building an ice pond, the property owner could choose the location, where it was not possible to choose the location of a river or lake, and thus elect to construct a pond in a more easily enforceable location, size, and shape.

The third category of parameters affecting the selection of property regimes is bargaining costs. Where a higher number of adjacent landowners decreased enforcement costs, it increased bargaining costs. Many adjacent landholders on a single pond meant that it was more difficult to get together and come to an agreement about ownership of ice. Taking all of these factors into account, whether explicitly or implicitly, individuals built property systems in natural ice.

In some respects the laws governing property rights in natural ice were consistent, however, they varied somewhat by state, especially on public water. Ownership of natural ice on lakes and ponds was the property of the lake bed owner, who was generally the owner of the adjacent land. On great ponds and lakes that were held in trust for the public, rights to harvest were determined by physical possession of the resource, which was open access. In 1879, New York passed a law governing the harvesting of ice on the Hudson River, which stipulated that an individual could establish rights to ice that formed over public waters by driving stakes into the ice, if that ice was between the individual's property and the center of the river[1]. In Illinois, owners of land adjacent to the Illinois River had property in the ice forming upon it to the middle thread of the stream, and needed only to respect public rights to navigability. In Iowa[2] and Massachusetts[3], ice on public water, including great ponds[4], remained subject to physical possession rules, and no rights could be established through staking. Great ponds in Maine were governed by similar laws[5].

In some instances, property rights to natural ice were defined by stakeholders without the existence of legal precedent. On Massachusetts's Fresh Pond in 1841, the owners of the shoreline, after conflict over ice harvesting rights, made the decision to hire an impartial local engineer to survey the pond and divide the ice harvesting rights thereto among the shore

[1] The owners of a mill pond own the ice formed upon it. The owner of the bed of a stream owns the ice within it…The state owns the Hudson river, in trust for the public. Apart from the statute about to be considered, the ice formed upon it, like the fish within it, becomes the property of the captor who first peacefully seizes it. Chapter 388, Laws 1879, provides that "the owners or occupants of lands and ice houses" on the Hudson River have the exclusive right of gathering ice formed on the river adjacent to the lands and ice houses so owned or occupied by them, after certain acts of appropriation are performed, such as staking out the ice field to be harvested. (*Slingerland v. International Contracting Co.*, 43 A.D. 215, 60 N.Y.S. 12 (1899))

[2] Actual possession of ice on public waters when fit to be cut, together with the present intention and ability to proceed at once to the harvest thereof, is necessary to constitute a legal appropriation thereof, and hence staking the banks of a stream before it has frozen, or marking, staking, or cleaning ice of insufficient thickness for harvesting, does not constitute a valid appropriation. (*Becker v. Hall*, 56 L.R.A. 573, 88 N.W. 324 (1901))

[3] Scraping off snow from the surface of the ice in a public pond, and driving stakes to indicate where the line of scraping is, give a person no title or right of possession to the ice included within the stakes, as against another who subsequently cuts and removes it...The owners of the shores have no exclusive rights in them except by a grant of the legislature. (*People's Ice Co. v. Davenport*, 149 Mass. 322, 21 N.E. 385 (1889))

[4] Ponds greater than ten acres in area.

[5] …The law governing ponds of more than 10 acres in extent, denominated "great ponds" by the colonial ordinance of 1641-1647, is different. Of no such individual owns the subjacent soil…Neither the shore proprietor, nor any corporation with simple charter authority to cut ice thereon, has any greater or different right…The one who first appropriates and secures the ice which is formed is entitled to it, and on the same principle that he who catches a fish in one of these rivers owns it. (*Barrett v. Rockport Ice Co.*, 16 L.R.A. 774, 24 A. 802 (1891))

proprietors (See Figure 3). Fresh Pond was, at the time, classified as a great pond, which was open access under the law. Forty years later, in an 1883 case (*Hittinger v. Eames*), the court ruled that the *de facto* ownership established by the shore inhabitants by surveying the pond did not confer *de juris* the right to exclude the public from harvesting ice there[6], and that the informal private property in ice established by adjacent landowners was actually open access.

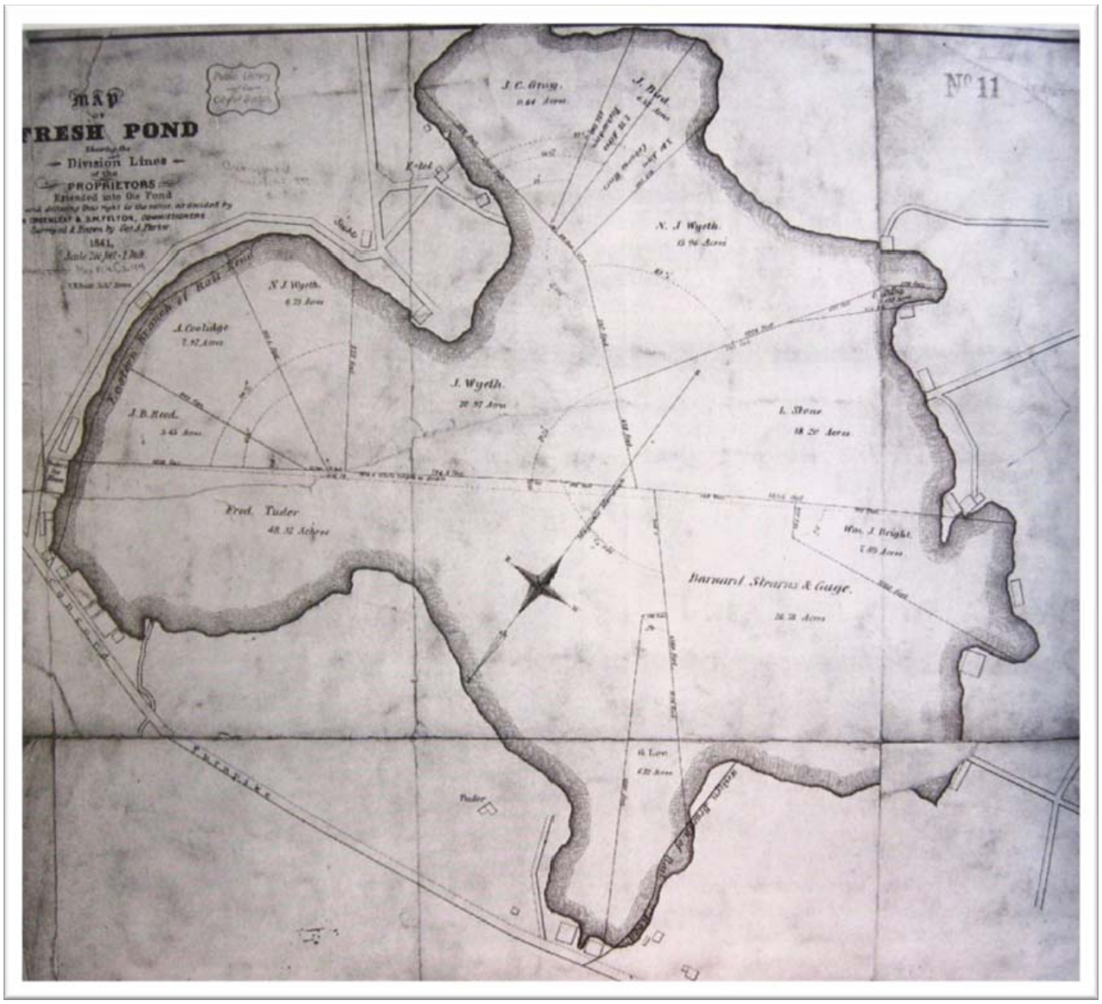


Figure 3: SURVEYOR'S MAP OF ICE HARVESTING RIGHTS ON FRESH POND

[6] "…owners of the shore of Fresh pond had, by an indenture, undertaken to divide the pond between themselves, and were accustomed at the beginning of the winter to scrape and mark off, by stakes, their respective shares of the pond; but the court held that they could not thus exclude the public from taking ice." (*Hittinger v. Eames*, 121 Mass. 539 (1883))

The Harvesting Process, Related Technology, and the Advent of Artificial Refrigeration

The harvesting process took place in three steps: clearing the ice, cutting it, and then transporting it to an icehouse for storage. To prepare a natural ice crop for harvest[7], first a horse-drawn plane or scraper was drawn across the surface of the ice in order to remove snow and porous ice. This served to clear the ice, but also to thicken it, as clearing the snow exposed the ice to colder air. Once ice reached al thickness of 30-35 cm, or about 12 inches, it was considered optimal for harvest (Thévenot 1979) because it could support the weight of men and the teams of horses that drew ice harvesting tools. Prior to the invention of the ice plow in 1825 by Nathaniel Wyeth, hand saws were used to cut irregular chunks of ice from a body of water. However, these chunks did not pack closely, and melted quickly. The horse drawn ice plow allowed for the cutting of uniform blocks of ice that packed closely, greatly reducing melting. The plow had two prongs about twenty inches apart which made parallel grooves in the ice. Drawn by horse, one prong of the plow was guided by a groove made on the previous pass in order to score the entire surface of a crop of ice in one direction, then perpendicular to the first set of grooves to form a grid, from which identical blocks of ice could be extracted. These blocks were then poled down a channel made through the ice towards the ice house elevator, which, powered first by horse, then later by steam, hoisted the blocks out of the water and into the ice house via slides. The total cost of this process averaged 25 cents per ton in 1883 (Anderson 1953). "The sleighs and cutting tools that were once horse drawn evolved into powered or steam driven cutters by the 1890s (Hill 22)."

Between its harvest in the winter months, and summer, when demand for ice surged, ice was stored in icehouses above ground near the place of harvest. Icehouses were usually double-walled and constructed of wood insulated with sawdust, and the largest could hold upwards of

[7] For images of ice harvest and the associated tools, see figures 15, 16, and 17 at the end of this thesis.

60,000 tons over two years, losing 10-25% to melting during that time period (Anderson 1953, Thévenot 1979). In order to preserve ice between winter harvesting and summer demand, ice houses were well insulated but allowed for drainage of water that melted off the ice.

Transporting ice to market was among the costlier inputs in natural ice production. Ice from lakes and ponds was loaded from icehouses into railcars at about 250 blocks or 5 tons per car for transport to nearby markets. Occasionally, a lake or pond was close enough to a river or stream to make water transit practicable, but otherwise harvesters on non-navigable waterways relied on the railroads to transport their ice to market. Where rail transit was available for lake and pond ice there was rarely more than one rail company, and freight costs were high compared to those paid for water transit. Ice harvested from rivers and streams was also stored in icehouses until the summer arrived, but then was loaded from the icehouse into a boat, which constituted the much less expensive transport alternative.

Once natural ice reached markets in the cities, it was dispersed to households and industries in ice wagons or ice trucks, some to breweries and cold storage facilities, and some to households. Ice sold to households was usually delivered at contracted seasonal or monthly rates for daily deliveries of 10-36 pounds, rather than by the ton or hundredweight (100 lbs.) (Anderson 1953).

The advent of artificial ice manufacturing occurred where conditions most warranted it: in breweries in the north, where artificial ice decreased industry-specific costs, and in the southern United States where prices for ice were high enough to make the technology practical. The first ice plants, constructed at the beginning of the 1870s, generally used ammonia absorption, while plants using ammonia compression for manufacturing ice became more common the 1880s and 1890s (Anderson 1953). In the northern states, the brewing industry was the first for which mechanical refrigeration was standard. Mechanical refrigeration did not fluctuate in price and availability, as natural ice did, nor did it require the space that natural ice required. Additionally, mechanical refrigeration allowed for more consistent temperatures and a drier, more sanitary environment, both of which allowed for the production of a higher quality product (Anderson 1953). The use of mechanical refrigeration in breweries in the 1870s, and by 1891 was standard technology. In the southern states natural ice could rarely be gathered, and people were forced instead to rely on shipments of ice from the north. This ice varied in price depending upon the conditions of the previous winter, and was $10-$30 a ton where the same ice retailed in the north for a fraction of that cost (Anderson 1953). Along with an unstable supply and variable prices, the Civil War contributed to the rise of the artificial ice industry. As conflict between the northern and southern states threatened regular ice shipments incentives to develop a local ice industry increased. By 1869 there were five ice factories in the U.S., located in the states of Louisiana, Texas and Tennessee. Ten years later, the number of ice factories in the U.S. had increased to 29 (Anderson 1953, Thévenot 1979), only one of which was in the northeast,

and by 1889, 165 ice plants existed in the southern United States (Anderson 1953). In contrast, the seven coldest northern states still had no artificial ice plants in 1900 (Thévenot 1979), and in 1909, natural ice still constituted a majority of the ice used in New York, Detroit, and Chicago.

Domestic refrigerators, which gained popularity in the late 1800s, first increased ice consumption (Anderson 1953) as more households had means to store and use it. The first domestic refrigerators were just ice chests, (Anderson 1953), but later models utilized ammonia compression. By 1884 refrigerators were "as common as stoves or sewing machines in all but the poorest tenements" (Anderson 1953) The meat packing industry in the Midwest pioneered the development and use of refrigerated railroad cars, in the last quarter of the 19th century

(Anderson 1953), which allowed their goods to reach many more markets via overland shipping. Natural ice remained competitive vis-à-vis artificial ice until World War I, after which electric motors enabled the creation of smaller domestic refrigerators, and the natural ice trade in the United States met its end (Weightman 2003).

Table 4: TIMELINE OF ARTIFICIAL REFRIGERATION TECHNOLOGY

1834	Jacob Perkins patents his vapor-compression-cycle refrigerator, the first patent for such a machine
1850	Dr. John Gorrie patents the cold-air machine
1860	Ferdinand P.E. Carré invents the ammonia absorption machine used for ice manufacture
1869	Ice plants begin to be used in the southern US for ice manufacture
1870	Mechanical refrigeration in breweries in the northern states begins, becoming standard technology in breweries by 1891
1877	Carl Linde, a German scientist, invents the first commercially successful mechanical ice machine
1880	Ice plants in the Southern US begin to threaten the New England ice trade to the area
1889-1890	Mild winters in the US create natural ice shortages and increase demand for artificial refrigeration
1895	Marcel Audiffren receives patents in several countries for his prototype of the domestic refrigerator
1926	General Electric sells two thousand domestic refrigerators
1950	Ninety percent of urban residents and eighty percent of the rural population use domestic refrigerators

Anderson (1953), Burstall (1965), Rees (2008), Weightman (2001)

III. Economic Theory

A. Literature Review

The analysis of the evolution of property rights has its theoretical foundation in the work of Coase (1960) and Demsetz (1967). Coase (1960) characterized factors of production as property rights, rights that allow the right holder to carry out a given set of actions, and pointed out that "[t]he cost of exercising a right (of using a factor of production) is always the loss which is suffered elsewhere in consequence of the exercise of that right," approximating the idea of externalities in property rights arrangements.

In his 1967 thesis, Demsetz proposed that "property rights arise when it becomes economic for those affected by externalities to internalize benefits and costs." Demsetz hypothesizes that people pursue property rights when they stand to gain more than they stand to lose from concentrating the effects of a given set of activities on the individual actors producing those effects. To support this thesis, he offered Eleanor Leacock's (1950) study of the Montagnes Indians, wherein Leacock noted that property rights among the Montages changed with the advent of the fur trade. Demsetz hypothesized that as the fur industry grew, the costs of overhunting in the existing system increased, and the benefits of husbandry (only incentivized under a system of private ownership) increased, factors which combined to swing the relationship between the costs and benefits of private ownership in favor of private property, and thereby causing its emergence.

The Demsetz thesis has two main implications on the allocation and use of natural resources. First, it establishes that private rights tend to produce more efficient resource use by concentrating the benefits and costs of resource use on individual users. In so doing, property rights produce incentives to maximize the value of a resource by determining optimal harvest time and quantity, rather than racing with other users to use a resource where no user has a right to exclude other users, and each user must harvest his share before the optimal time. Second, Demsetz' thesis asserts that property rights go further to increase the efficiency of resource use by decreasing contracting costs—the time and effort required to reach an agreement on resource use between competing users. Under common property arrangements, all users must reach an agreement, a process significantly more costly than that required to reach an agreement among a smaller number of private rights holders.

After Demsetz' 1967 thesis, the literature on the evolution of property rights can be broken down into three areas of study. The first focuses on the factors influencing the evolution of property rights and the selection of property systems, the second studies the costs and benefits of the property rights creation process itself, and the third examines sources of property rights.

One body of literature examines the factors that influence the selection and modification of property rights regimes. Notable in this area is the Anderson and Hill (1975) study of factors influencing the creation of property rights to land, livestock, and water in the American west. Also relevant is Ellickson (1993) which argues that homogenous users can more easily come to agreements over property regimes saying that "a close-knit group tends to create, through custom and law, a cost-minimizing land regime that adaptively responds to changes in risk, technology, demand, and other economic conditions," variably choosing land regimes ranging from private ownership to open access where each given system is optimal. Examining what appeared to be a refutation of the Demsetz thesis, Lueck (2002) analyzed the American bison and the near extinction of the species, finding that, rather than an failure of property rights systems to respond to changing costs and benefits, in the case of American bison the failure of private property to emerge was in fact efficient, given the advent of cattle ranching and the changes it brought in the costs and benefits of maintaining the bison stock. These studies strengthen the foundation of the Demsetz thesis through offering empirical evidence in its support.

The second category of literature arises in response to economic analyses of the costs and benefits of the property rights creation process itself. In answer to the idea that a race to establish property rights can dissipate rents, Elinor Ostrom (1991) examines the relative costs and benefits of allowing user groups to determine property arrangements rather than deferring to a state apparatus for the creation of property rights, arguing that individual user groups more familiar with local circumstances act to establish more efficient and effective property rights arrangements—including common ownership—than a bureaucracy seeking to establish property rights. Lueck (1995) examined the role of the common law in anticipating and mitigating rent dissipation associated with first possession rules. Anderson and Hill (2002) studied the role of entrepreneurs in finding new, valuable aspects of a resource to privatize, finding additionally that small, homogenous groups are more efficient at establishing and organizing valuable property rights—without dissipating the associated rents—than centralized processes. A central theme in this literature is the importance of considering the costs and benefits of the property rights creation process itself.

The third category of literature examines sources of property rights. In his 2002 expansion of his original thesis, Demsetz puts forth the idea that property rights do not only emerge as a response to changes in the costs and benefits of internalizing externalities, but also through institutions, giving the example of theft and taxation, noting that when theft is minimized through institutional change, financial returns on production increase without changing the "technical rate at which inputs can be converted to outputs." According to Demsetz, this alternative source of private property acts to make a system of private enterprise work, and

Demsetz implies that private rights would exist even without efforts to internalize externalities. In recognition of alternative sources of property rights, Banner (2002) noted that property regimes, whether efficient or not, are a political decision, and do not necessarily arise purely from the costs and benefits associated with establishing property rights, but despite this fact the selection of property regimes tends towards efficiency. This area of study incorporates the role of institutions in determining property rights arrangements.

All three areas of study are relevant to my analysis. I propose that property rights in natural ice do evolve as an effort to internalize externalities, and that an adaptive legal system providing protection for property rights—which itself arises depending upon the costs and benefits of this process—plays a critical role in subsequent economic growth: that the gains from a system that allows for the evolution of property rights are multiplied when an adaptive legal system can help ensure the security of those rights. In the example of natural ice on New York's Hudson River, custom dictated rights to ice on the waterways in New York, and owners established their rights through staking ice. While these rights were not as secure as legal rights, they were an improvement over open access. As the industry developed, law dictated ownership of ice on the Hudson River according to these rules. Customary rules establishing property rights were incorporated into the legal system, which subsequently allowed for significant development of the industry.

Gordon (1954) pointed out the contrast between resource use under open access and under private property regimes: the incentives each create, and that open access tends to cause rent dissipation, or resource use at a level where average cost is equal to average benefits, rather than a level at which marginal cost is equal to marginal benefit. De Alessi (2003) later pointed out the incentives that open access fails to create: "Open access is especially problematic because it discourages investment in activities which would increase the value of a resource over time. A private owner would have an incentive to undertake such an activity if the net present value of the future stream of rents (to which he would have sole rights) outweighed the cost of the activity." While the choice of a particular property regime affects the incentives associated with resource use, there are also incentives that affect the choice of property regimes in the first place. Demsetz (1967) famously discussed the concept of transaction costs, and their role in the property rights determination process. He argues that property rights emerge when their benefits outweigh their cost, but adds that transaction costs can tip the balance in favor of open access, as users find the total costs of property rights, that is enforcement plus transaction costs, exceed the benefits. Libecap (2002) uses the example of oil and gas unitization to emphasize that optimal property rights arrangements are more likely to emerge in homogenous groups, where users have similar views on resource value, and thus contracting costs are lower. This body of property rights theory assumes that agents choose the property regime that maximizes rents minus enforcement and transaction costs, and forms the basis of my analysis.

B. Model

The choice of property rights in natural ice is an economic one, and thereby depends on an array of economic variables, each of these having its own effect on the selection of property regimes. In order to analyze the relationship between economic choice and economic variables, a property rights model will be used. To examine the effects that individual parameters have on property rights to natural ice I will take an empirical approach, examining property rights to natural ice in the U.S. as recorded in legal cases between 1879 and 1915.

In order to construct a model of the costs and benefits of private property in ice, we can use a harvest effort framework, where the y-axis represents costs, or revenues, in dollars, and the x-axis represents harvest effort. Assuming agents are maximizing rent, optimal effort level is found at the intersection of marginal cost and marginal revenue curves. Cost and price affects can be considered in order to construct a model comparing private property and open access in ice. A change in the cost of ice harvesting could be produced by such events as the invention of the ice plow. As illustrated below, the decrease in marginal cost as a result of improvement in technology increases rent from R to R_1.

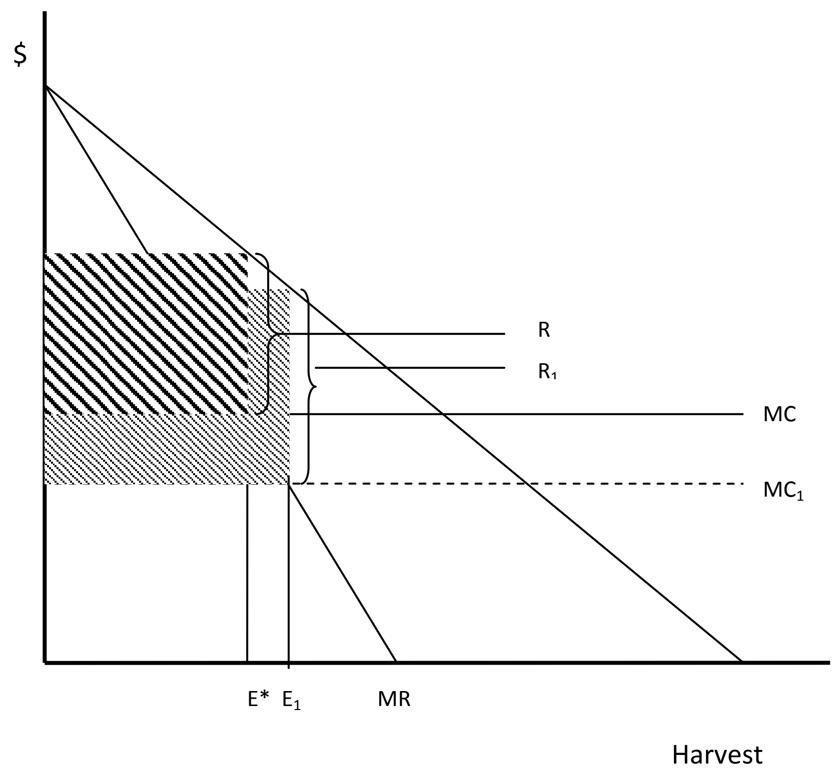


Figure 5: COMPARATIVE STATICS FOR COST EFFECTS

In addition to cost affects, there are also price affects within this framework. Property regimes aside, an increase in the price of ice would increase marginal revenues, which, in turn would increase rent from R to R_1 as illustrated in the following figure.

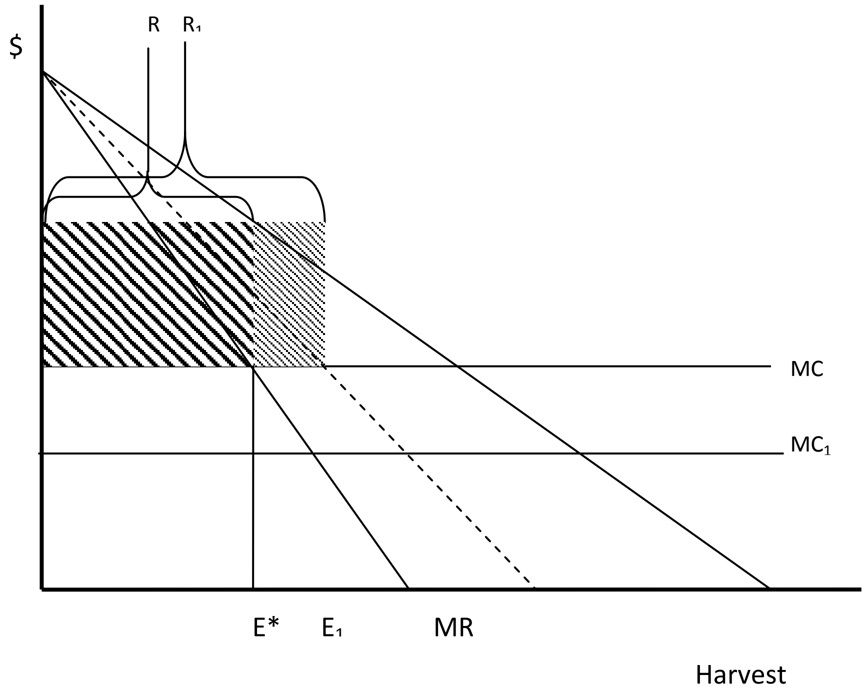


Figure 6: COMPARATIVE STATICS FOR PRICE EFFECTS

Within this framework, many predictions about which property regimes will arise where can be formed. Analysis is limited by available data, but the following predictions can be evaluated based on the data collected.

Prediction 1: Ice on artificial bodies of water is more likely to be private property than ice on natural bodies of water

Recounting De Alessi (2003), a private property owner has an incentive to undertake activities that increase the value of a resource because that owner can expect to capture all of the related rents. This is important with respect to artificial bodies of water. Where ponds are constructed specifically for the harvesting of ice, said ponds would not be constructed if the owners did not have reason to believe that they could harvest ice profitably. Under these conditions revenue minus harvest, enforcement and transaction costs are likely to be positive. In the case of ice ponds, private property probably precedes ice pond construction, such that all ice ponds are likely to be private property. On millponds the costs and benefits of a given property regime will be slightly different. A millpond, a pond formed by a milldam for the purpose of producing hydropower, is herein taken to be an artificial body of water. While the costs of reaching agreements, for example about water level, increase total cost of ice harvesting, costs are likely still likely to be low enough to incentivize a system of private property, given that similar incentives to those associated with constructing ice ponds also apply for the construction of milldams.

Additionally, unlike the case of rivers and navigability, in the case of millponds the competing uses (hydropower and ice) are compatible uses (mill during summer, ice during winter), and thus the users are more homogenous. For this reason property rights can be bundled, and transaction costs on artificial bodies of water are spread over two profitable activities, decreasing the marginal transaction cost to the level MC_1. Since users can, at least to some limited extent, choose the location of an artificial body of water, they are more likely to be located in an easily enforceable area, a further decrease in enforcement costs to MC_2. The marginal cost of transportation in the case of artificial bodies of water are likely to be higher, as the ice harvested under these conditions is likely to require additional effort to move it to a navigable waterway, or to transport it by rail, increasing marginal costs to MC_3. Finally, the quality of ice on artificial bodies of water is likely to be higher, as rights-holders are more likely to be able to control the environment surrounding the ice, and prevent pollutants from entering the water, which increases marginal revenues to the level MR_1. The net result is higher rents on artificial bodies of water, which creates greater incentives for private property. Rent associated with artificial bodies of water is R_1 in the illustration.

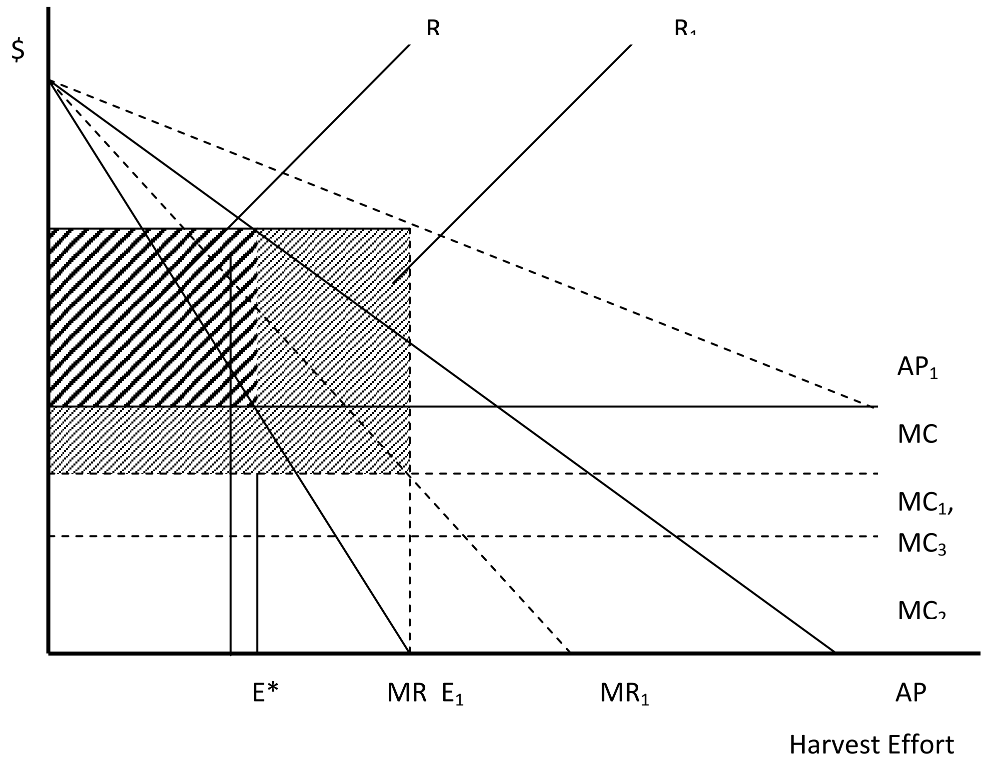


Figure 7: COMPARATIVE STATICS OF ARTIFICIAL AND NATURAL BODIES OF WATER FOR ICE HARVEST

Prediction 2: Ice on non-navigable water is more likely to be private property than ice on navigable waterways

On navigable streams and rivers, the competing use—transportation—is very valuable and users are numerous and heterogeneous, so contracting costs are high (MC_1). Unless ice is very valuable, or navigability can be preserved without conflict with ice harvesting, as is the case on large rivers, ice on navigable waterways is likely to be open access. Furthermore, on navigable waterways enforcement costs are high, as there is a higher density of users on them, further raising marginal cost to MC_2. On the other hand, ice forming over moving waters is marginally clearer, and thus more valuable, increasing marginal revenue to MR_1; and transportation costs are much lower, decreasing marginal costs to MR_3, as ice on navigable waterways can be readily transported by water. Rent associated with navigable waters is R_1 in the illustration.

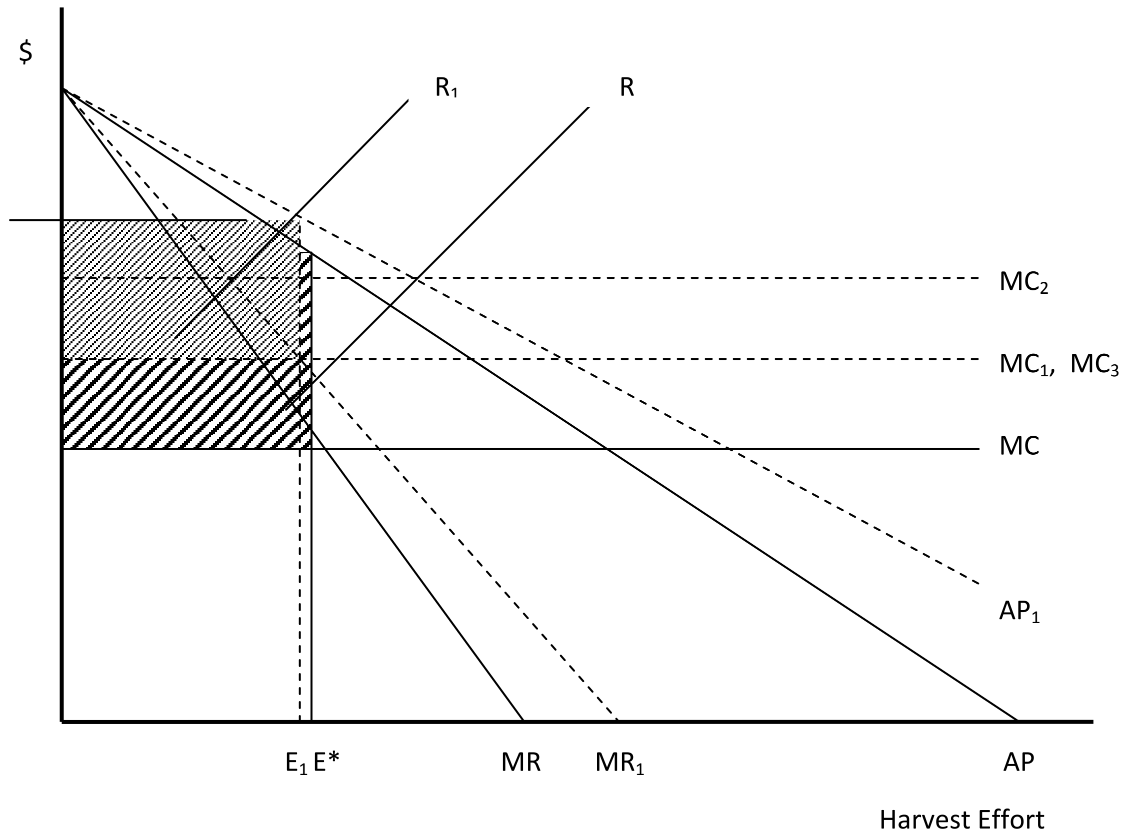
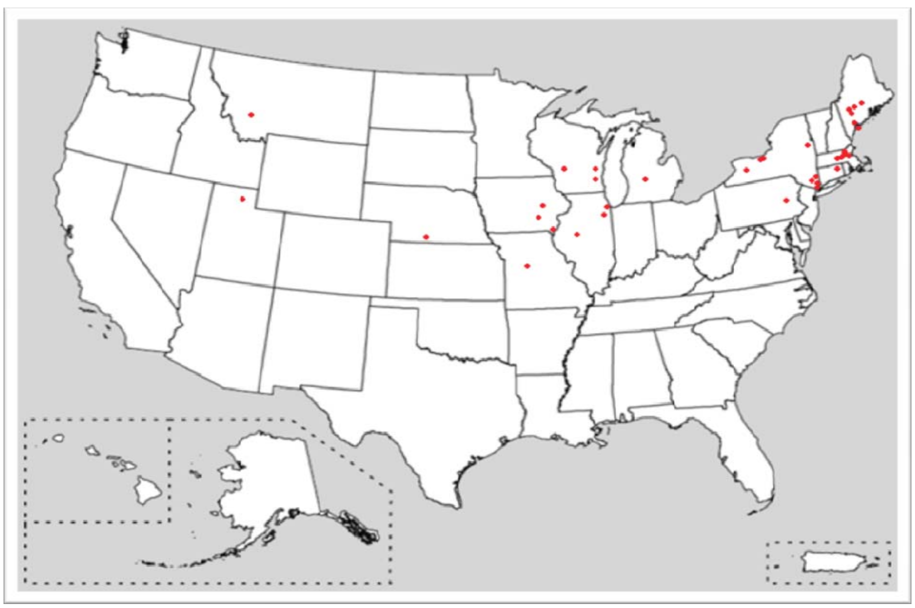


Figure 8: Comparative Statics of Navigable and Non-Navigable Waters for Ice Harvest

IV. Empirical Analysis

Ideally, in order to test a hypothesis about the relationship between property regimes and explanatory variables a data set would be assembled to include details on the price of ice at different markets, year-to year weather variations, and changes in harvesting and storage technology. Additionally, data on freight rates for different methods of shipping and the distance from an ice harvesting location to market, and values of ice rights purchased could be included. While it is difficult to collect such detailed data for time periods before extensive records were kept, a simple analysis comparing data on ownership, resource characteristics, and navigability can still be conducted.

For this analysis I use data collected from sixty court cases published between 1879 and 1915, in addition to temperature data from the national weather service[8]. Of the sixty cases, thirty five contained enough information to complete an analysis (See Figure 9 for locations of observations). Cases in which ice is private property are overrepresented in the data set, at twenty six of thirty five.[9] I examine patterns in property regimes vis-à-vis each parameter—artificial vs. natural bodies of water, navigable vs. non-navigable waters, and colder vs. warmer winter temperatures. The two categories of property regime described earlier in this study are compared to two values for a given parameter. If property regimes are uncorrelated with the parameter, we would expect an equal dispersion across all quadrants. However, if there is a relationship between parameter and economic choice, dispersion would be concentrated more in some quadrants than in others.



Map source: http://commons.wikimedia.org/wiki/File:Map_of_USA_showing_unlabeled_state_boundaries.png

Figure 9: LOCATIONS OF ICE RESOURCES APPEARING IN LEGAL CASES EXAMINED IN THIS STUDY

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[8] A full data summary appears at the end of this thesis.

[9] One explanation for this may be that open access is the default property regime when a resource has been little used or is not valuable, and that disputes over property rights that become legal precedent are thus more likely to arise when users convert from an open access system to private property.

Table 10: SUMMARY OF PREDICTIONS

PARAMETER	MARGINAL REVENUE	HARVEST AND TRANSPORTATION COSTS	TRANSACTION COSTS	ENFORCEMENT COSTS	NET EFFECT
Artificial (vs. Natural)	+	+	-	-	private property
Navigable (vs. Non-navigable)	+	-	+	+	ambiguous

A. Artificial bodies of water and ownership

Based on higher harvest and transportation costs, lower transaction and enforcement costs, and higher marginal revenue, it was predicted that ice on artificial bodies of water would be private property. As the data summary shows, of 35 cases for which data on ownership and resource details were both available, ice on all but one artificial body of water was private property (the exception was ice on a government canal). Ice on natural bodies of water was fairly evenly split between private property and open access. While this is consistent with the prediction based on marginal costs and benefits, the parameter (Artificial/Natural) is probably not exogenous, as it is probable that property rights institutions had an effect on where people chose to harvest ice in the first place, for example, where two locations are available for the construction of a dam, the location with more secure property rights would probably be chosen. In order to make a more meaningful assessment, data on when private property was established as compared to when ice harvesting began at a particular location would be necessary.

Table 11: PATTERNS OF ICE OWNERSHIP ON ARTIFICIAL VS. NATURAL BODIES OF WATER

	Artificial	Natural	Total
Private property	20	6	26
Open access	1	8	9
Total	21	14	35

B. Navigability and ownership

Based on assumptions of higher transaction and enforcement costs, lower harvest and transportation costs, and higher marginal revenue, it was predicted that ice on non-navigable water was more likely to be private property. In the 35 cases examined, ice on non-navigable waterways fell under private property a majority of the time (21 of 25 observations). Ice on navigable waterways was evenly split between private property and open access. Ice on non-navigable water was thus more likely to be private property, as per the prediction; however, this relationship is not mirrored by open access on navigable waterways. One possible explanation is that on large waterways navigability can be preserved while the resource is still being utilized for ice harvesting, a situation of lower transaction costs. Another possible explanation is that locations on large, navigable rivers were ideal places for cities, especially before non-water transportation infrastructure was available. For this reason, large rivers were more likely to have historically existing, evenly represented property regimes and enough competing users to make reversing property regimes to open access difficult.

Table 12: PATTERNS OF ICE OWNERSHIP ON NAVIGABLE VS. NON-NAVIGABLE WATERS

	Navigable	Non-navigable	Total
Private property	5	21	26
Open access	5	4	9
Total	10	25	35

C. Chi squared test and statistical significance

If property regimes were not influenced by the previously discussed parameters, one would expect the distribution of property regimes to be relatively evenly distributed between private property and open access. The statistical significance of the deviation of the results from a random distribution can be determined using a chi squared test of the data, with H_0: property regimes are randomly chosen. When df = 1, where O_i is the value in category "Private property," E_i is $\frac{n}{2}$, the chi squared statistic is given by the formula $X^2 = \sum \frac{(O_i - E_i)^2}{E_i}$.

The chi-squared test reveals statistical significance at the 10% level for the effects of the artificial/natural and navigability parameters, but not for winter temperatures, as summarized in the table below.

Table 13: CHI-SQUARED TEST

	PRIVATE PROPERTY	OPEN ACCESS	N	CHI SQUARED STATISTIC	REJECT THE NULL HYPOTHESIS* AT 10% SIGNIFICANCE LEVEL?**
Artificial	20	6	26	3.77	Yes
Natural	1	8	9	2.72	Yes
Navigable	5	21	26	4.92	Yes
Non-navigable	5	4	9	0.06	No

*H_0: Property regimes in natural ice are randomly selected.
***The 10% critical value with df = 1 is 2.71*

V. Summary and Conclusions

In this thesis I have put forth an economic model for the analysis of the structure of property rights in natural ice. I have illustrated that property rights systems in natural ice are not randomly assigned, but that they are an economic choice dependent upon economic variables. Following Demsetz "property rights arise when it becomes economic for those affected by externalities to internalize benefits and costs." In natural ice, the choice of property rights systems was affected by the relative costs and benefits of characteristics such as navigability, and whether the body of water on which ice formed was artificial or natural. In addition, private property rights emerged as a result of technological change. Indeed, the major growth of the industry as a whole, along with legally supported property rights to ice, did not happen until a significant change in technology—namely the invention of Wyeth's ice plow in 1825—had occurred, lowering the costs of harvesting ice, and thus increasing the benefits of private property rights.

How do the characteristics of individual bodies of water influence the decision to create private rights? While no causation can be assumed from the correlation found, the data show that ice on artificial, non-navigable bodies of water is more frequently private property, with rights holders having claim to the ice from year to year, and those rights supported by legal precedent. These are unlikely to be the only factors affecting the choice of property regimes, and with a larger, more comprehensive data set, stronger conclusions and conclusions about additional parameters could be drawn.

By examining the forces behind the creation of property rights and establishing connections between specific parameters and the choice to establish a system of private property rights I create a framework that can be used to analyze 1) how private property influences resource use and averts rent dissipation, 2) how private property contributes to the development of industry and investment that increases resource value over time, and 3) what happens to property rights when an industry dissolves. With industry data and data collected on specific legal cases one might investigate how legal precedent influences the dispersion and development of industry.

While I have examined the evolution of property rights to natural ice as property rights to ice arose, I have done little examination of the other end of that evolution: the eventual demise of those rights. What is evident is that the bodies of water on which the majority of ice was harvested have since been appropriated as municipal water supplies, or are otherwise held in trust for the public for navigation or other uses. What is not evident is the process by which this transfer of rights occurred, the decisions made by economic agents and the reasons for those decisions. With more time, an examination of the reversal of property rights in natural ice could be conducted, which could shed light on what happens to rights over natural resources when those resources decrease significantly in value. This, in turn, could be used as the basis for understanding the transition of property rights in other natural resources when alternatives to those resources are discovered, what, if any, action should be taken in reallocation or rebundling of property rights, and the implications of these decisions.

Table 14: Data Summary

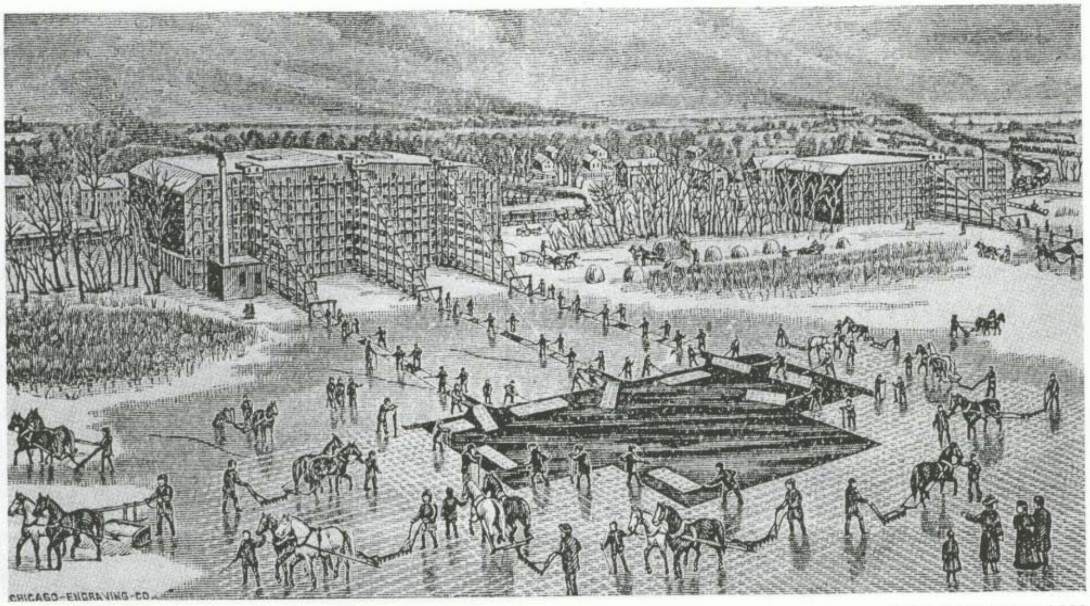
Case	Location	Ownership	Artificial/ Natural	Navigable/ Non-navigable
Stevens v. Kelley and another 78 Me.445, 6 A. 868	Pond (Augusta, Maine)	private property	artificial	non-navigable
Gregory v. Rosenkrans 1 L.R.A. 176, 39 N.W. 378	Millpond (Palmyra, Wisconsin)	private property	artificial	non-navigable
Charles C. Wilson & son et al v. Harrisburg et al. 107 Me. 207, 77 A. 787	Androscoggin River (Lewiston, Maine)	private property	natural	navigable
Klenzing, Appellant v. Allday 63 Pa.Super. 304, 1916 WL 4551	Artificial ice pond (Pennsylvania)	private property	artificial	non-navigable
E. G. Beechwood Ice Co. v. American Ice Co. 176 F. 435	Barberry Creek (Portland Harbor, Maine)	private property	artificial (dammed)	non-navigable (dammed)
Washington Ice Co. v. Shortall 101 Illinois 46	Calumet River (Calumet, Illinois)	private property	natural	navigable
Whittemore Rowell & others v. Jeremiah Doyle 131 Mass. 474, 1881 WL 11343	Chauncey (Great) Pond (Northborough, Massachusetts)	open access	natural	non-navigable
Jesse Dyer v. Norris G. Curtis 72 Me. 181	Mill pond (Cape Elizabeth, Maine)	private property	artificial	non-navigable
Board of Park Commsrs. v. Diamond Ice Co. 130 Iowa 603, 105 N.W. 203	Des Moines River (Des Moines, Iowa)	open access	natural	navigable
Hittinger v. Inhabitants of Westford 135 Mass. 258, 1883 WL 10970	Forge (Great) Pond (Westford, Massachusetts)	open access	natural	non-navigable
Hittinger v. Inhabitants of Westford 135 Mass. 258, 1883 WL 10970	Fresh (Great) Pond (Cambridge, Massachusetts)	open access	natural	non-navigable

Dansinger et al. v. White 64 Hun 636, 19 N.Y.S. 897	Glen Lake (Glens Falls, New York)	private property	natural	non-navigable
Becker v. Hall 56 L.R.A. 573, 88 N.W. 324	Government canal at Keokuk (Keokuk, Iowa)	open access	artificial (government canal)	navigable
American Ice Co. v. Catskill Cement Co. 43 Misc. 221, 88 N.Y.S. 455	Hudson River (New York)	private property* (first right, but still have to stake each year)	natural	navigable
Van Rensselaer et al. v. Moul 48 Hun 396, 1 N.Y.S. 28	Hudson River (New York)**	open access	natural	navigable
Farr v. Griffith 9 Utah 416, 35 P. 506	Ice ponds (Weber County, Utah)	private property	artificial	non-navigable
Rock Island & P. RY. Co. v. Leisy Brewing Co. et al. 174 Ill. 547, 51 N.E. 572	Illinois River (Lake Peoria) (Peoria, Illinois)	private property	natural	navigable
Marshall Ice Co v. La Plant 136 Iowa 621, 111 N.W. 1016	Iowa River (Des Moines, Iowa)	private property	artificial (dammed)	non-navigable (dammed)
Chicago & Eastern Illinois Railroad Company v. William R. Shelby 42 Ill.App. 339, 1891 WL 2146 (Ill.App. 2 Dist.)	Kankakee River (Momence, Illinois)	private property	artificial (dammed)	non-navigable (dammed)
Fischer v. Missouri Pac. Ry. Co. 135 Mo.App. 37, 115 S.W. 477	Lake (Sedalia, Missouri)	private property	artificial	non-navigable
In re Daly, Commissioner of Public Works 123 A.D. 709, 108 N.Y.S. 635	Lake Glenaida (New York)	private property	artificial (dammed)	non-navigable (dammed)
Barrett v. Rockport Ice Co. 16 L.R.A. 774, 24 A. 802	Lily (Great) Pond (Farmington, Maine)	open access	natural	non-navigable
Hazelton v. Webster 20 A.D. 177, 46 N.Y.S. 922	Lime Lake (Machias, New York)	private property	artificial (lake with mill dam)	non-navigable
Abbott v. Cremer et al 118 Wis. 377, 95 N.W. 387	Millpond (Monroe County, Wisconsin)	private property	artificial	non-navigable

Lawton v. Herrick 83 Conn. 417	Millpond (Windham County, Connecticut)	private property	artificial	non-navigable
Lepper et al v. Wisconsin Sugar Co. 146 Wis. 494, 128 N.W. 54	Millpond off Menomonee River (Waukesha County, Wisconsin)	private property	artificial	non-navigable
Green Island Ice Co. v. Norton 42 Misc. 238, 86 N.Y.S. 613	Mohawk River (Erie and Champlain canal system) (New York)	private property (permits issued by canal authority)	natural	navigable
Richter v. Linden 45 Mont. 269, 122 P. 918	Ice ponds (Butte, Montana)	private property	artificial	non-navigable
Hudson River Ice Co. v. Brady 158 A.D. 142, 142 N.Y.S. 819	Murderer's Creek (navigable Hudson tributary) (New York)	open access	natural	navigable
Woodman v. Pitman and others 79 Me. 456, 10 A. 321	Penobscot River (Bangor, Maine)	open access	natural	navigable
In re Simmons et al.. Board of Water Supply of City of New York 139 A.D. 273, 123 N.Y.S. 1034	Pond (Westchester County, New York)	private property	artificial	non-navigable
McCollum v. Williamson et al. 96 A.D. 638, 89 N.Y.S. 119	Pond adjacent to Erie Canal (New York)	private property	artificial	non-navigable
Mansfield v. Place 18 L.R.A. 39, 93 Mich. 450, 53 N.W. 617	Prairie Creek Pond (Ionia, Michigan)	private property	artificial (dammed)	non-navigable
Eidemiller Ice Co. v. Guthrie et al. 28 L.R.A. 581, 60 N.W. 717	Republican River (mill pond) (Nebraska)	private property	artificial	non-navigable
Walker v. American Steel & Wire 185 Mass. 463, 70 N.E. 937	Salisbury Pond (Worcester, Massachusetts)	private property	artificial	non-navigable

* riparian owner has the first right, but still must stake to indicate intent to harvest

** there are two observations for the Hudson River, but as one falls under private property and the other under open access both have been retained

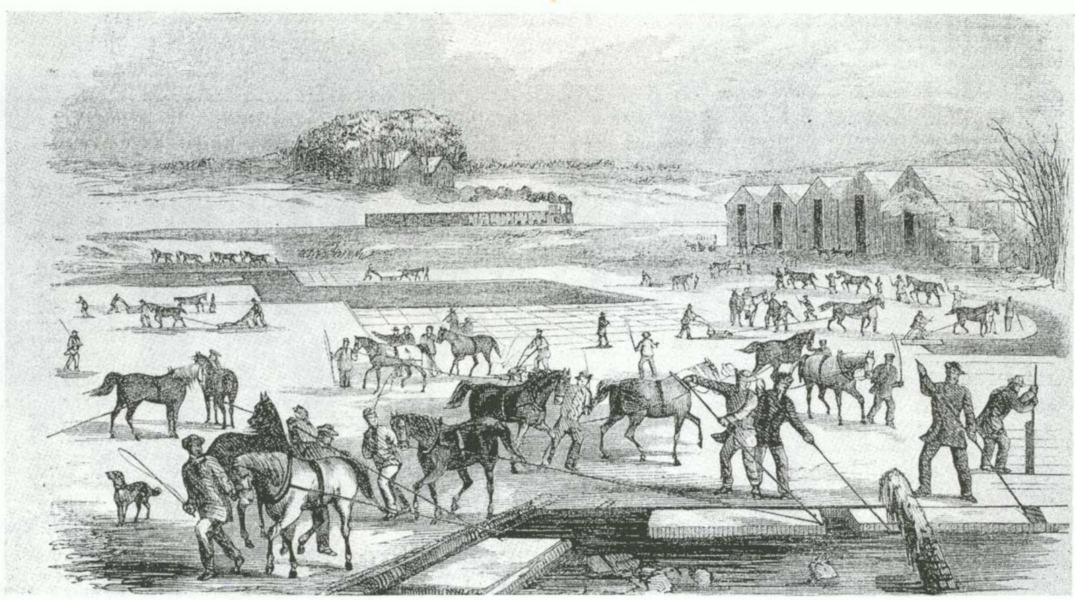


Lakeside Directory, 1889

HARVESTING, INDIANA, 1889

Steam-powered conveyor chains elevated ice at these structures maintained by a Chicago ice firm at Wolf Lake, Indiana.

Figure 15 Image credit: Cummings



Gleason's Drawing Room Companion, 1852

HARVESTING, MASSACHUSETTS, EARLY 'FIFTIES

Specially designed freight cars carried mid-century harvests from Fresh Pond and Spy Pond to Boston. Train is shown in background.

Figure 16 Image credit: Cummings

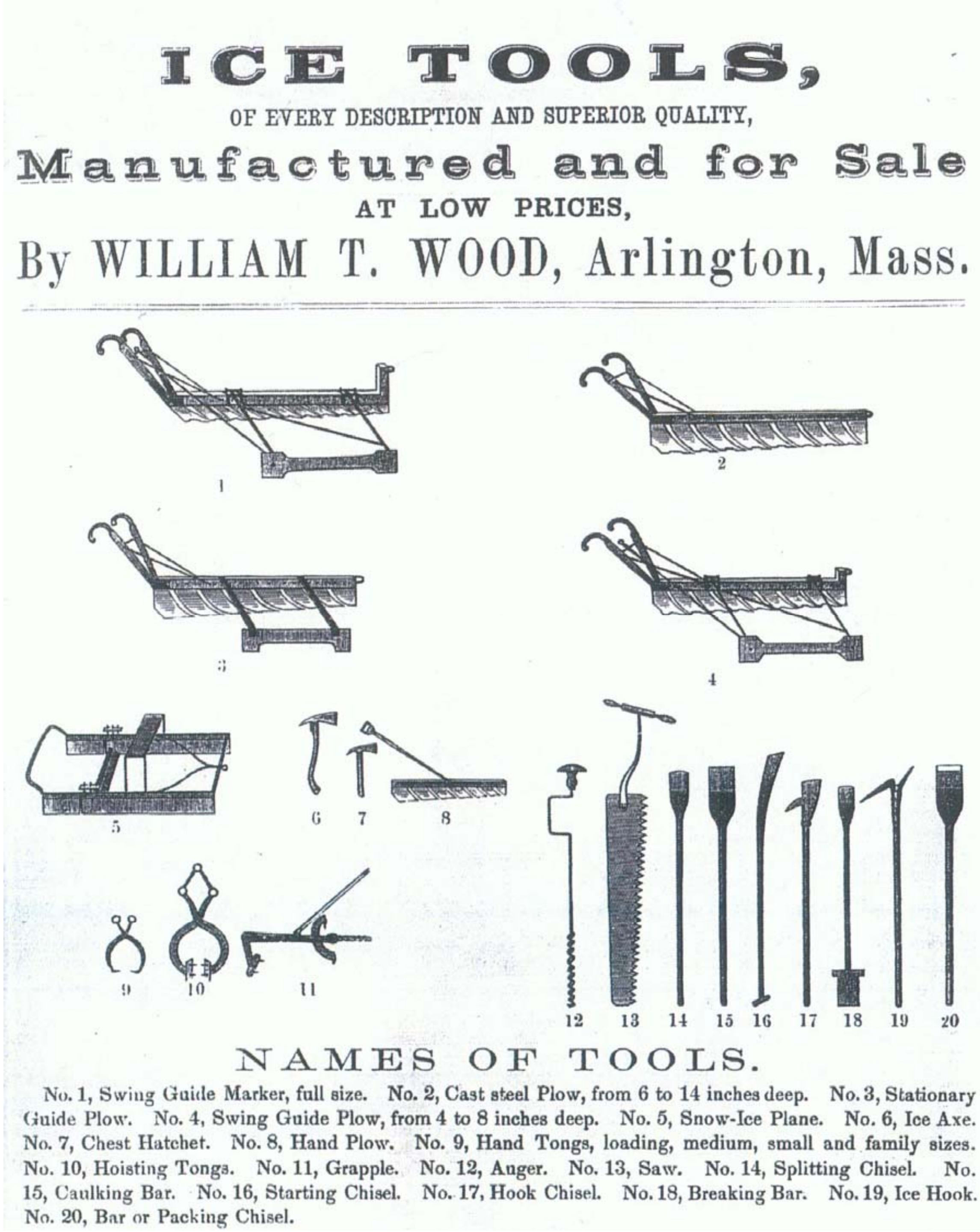


Figure 17 Image credit: Weightman

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