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Working Paper

Early Weather Information, Cost That May Be Sunk, And The Ensuing Rate of Return

Working Paper, No. 125

Provided in Cooperation with:

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Suggested Citation: Craft, D. Erik (1996) : Early Weather Information, Cost That May Be Sunk, And The Ensuing Rate of Return, Working Paper, No. 125, The University of Chicago, Center for the Study of the Economy and the State, Chicago, IL

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Early Weather Information, Costs That May Be Sunk, And The Ensuing Rate of Return

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George J. Stigler Center
for the Study of
the Economy and the State

The University of Chicago

WORKING PAPER SERIES NO. 125

**Early Weather Information, Costs That May Be Sunk,
And The Ensuing Rate of Return**

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February 1996

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JEL Codes: H4, N7

Keywords: Early weather information. Transportation cost. Cargo insurance. Cargo rate.
Storm warnings. Shipping losses. Public good.

"Early Weather Information, Costs That May Be Sunk, And The Ensuing Rate Of Return"

The United States Federal government established a national weather organization in 1870. Previous attempts by private individuals and quasi-public organizations had been unsuccessful in selling weather information or raising funds to support a forecasting service. Changes in the seasonality and level of cargo insurance rates and cargo shipping rates, as well as an analysis of Great Lakes cargo and hull losses, provide evidence of the value of storm warnings on the Great Lakes. Nearly half of the Great Lakes storm warning display stations were closed during the fall of 1883 on account of appropriations reductions due to an embezzlement scandal in the Army Signal Service. This natural experiment permits the econometric estimation of the value of storm warning display locations on the Great Lakes and the calculation of a rate of return minimum bound for weather service expenditures during the Weather Bureau's founding period.

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February 1996

I wish to thank Raaj Sah, David Galenson, and especially Lester Telser for guidance and inspiration while working on this dissertation topic. Robert W. Graham and staff at the Institute for Great Lakes Research generously led me through its collection of Great Lakes records. I am also thankful for the assistance of Paul Woehrmann and the Great Lakes collection at the Milwaukee Public Library. Gerald Marschke, Philip Hoffman, an anonymous referee, and participants at the University of Chicago Applied Price Theory Workshop and a Cliometrics Society Allied Social Sciences Association session offered helpful comments.

I. INTRODUCTION

The importance of government investment for economic growth has been an issue of contention in understanding both the historical development of the United States and the appropriate role of the state today. Even such a questioning author as Coase [1974] assumes that lighthouse services, whose method of provision he critically studies, provide benefits exceeding costs. Given that a state's resources may be limited and that the social cost of publically financed projects may exceed the private cost, our understanding of the optimal provision of services, both in the past and present, is not complete without rate of return estimates and marginal analysis.

Fogel [1960], for example, estimates the minimum social rate of return of Union Pacific Railroad construction expenditures by adding the value of increased land rents to Union Pacific earnings. Ransom [1970] calculates rate of return estimates for public canal construction in the Ohio Valley also by assessing the rents from reduced transportation costs. Griliches [1958] uses estimates of future corn yields and the counterfactual case of a world without hybrid seed corn to calculate a lower bound on the social rate of return to combined public and private hybrid corn research expenditures. This paper estimates a minimum bound on the social rate of return to the creation and distribution of weather information during the founding period of the United States Weather Bureau. Specifically, I shall offer three types of evidence that weather information on the Great Lakes lowered the costs of transportation. I shall estimate directly the value of the Weather Bureau's storm warnings using an econometric analysis. This exercise also will estimate the marginal value of additional storm warning display locations. Changes in the level and seasonality of cargo insurance rates and shipping rates from Chicago to Buffalo offer further support for the hypothesis that storm warnings were valuable and are broadly consistent with the econometric estimates.

The United States Congress established a national weather organization in 1870 when it instructed the Secretary of War to organize the collection of meteorological observations and forecasting of storms on the Great Lakes and Atlantic Seaboard. See Craft [1995], Fleming [1990], Alter [1949], and Abbe [1871]

for details of prior attempts to organize and to sell weather information. In addition to preparing storm warnings for mariners, the United States Army Signal Service expanded services in 1872 to include agricultural and commercial interests [Whitnah 1961]. New services included general weather forecasts and flood and cold warnings. After years of debate on the appropriate organization of a Federal weather service, Congress moved weather forecasting responsibilities from the War Department to the Agriculture Department in 1892.

Weather information can affect markets in at least three ways: it can provide forecasts with which economic agents alter behavior to maximize profits or utility, it can provide climatic data with which agents match varieties of crops or methods of production with different regions more efficiently, and it can provide post-occurrence data with which markets may signal relative scarcities sooner, thereby leading to more efficient consumption streams of weather-sensitive commodities. The focus of this paper will be the first of these uses of weather information, storm warnings on the Great Lakes.

A reduction in the Army Signal Service budget in fiscal year 1883 on account of an embezzling scandal caused the number of storm warning stations on the Great Lakes during the fall of 1883 to fall by nearly one half, thereby offering a natural experiment with which to estimate the value of the storm warnings. If severe weather forecasts on the Great Lakes were valuable transportation inputs, one would also expect insurance and shipping rates to change after the introduction of the new service. Specifically, the differences between rates during peaceful summer months and relatively stormy fall months should diminish.

This paper seeks to provide credible evidence of the high rate of return from the creation of weather information by the Federal government. A complementary product of this research has been a better understanding of the history of Great Lakes shipping. Section Two will provide background information on both shipping and early Signal Service weather activities on the Great Lakes after the Civil War. Section Three will estimate econometrically a relationship between the availability of weather

information on the Great Lakes and its value. Section Four offers corroborating evidence of the value of weather information in the form of cargo insurance data. Section Five presents a history of grain cargo rates from Chicago to Buffalo which is consistent with the hypothesis that storm warnings were socially valuable. Section Six combines estimates of the value of storm warnings on the Great Lakes with previously derived cost data to calculate a minimum bound for the rate of return to United States and Canadian weather information expenditures from 1870 to 1888. Section Seven provides the conclusion.

II. SHIPPING AND WEATHER INFORMATION ON THE GREAT LAKES AFTER THE CIVIL WAR

This paper estimates the value of early weather information on the Great Lakes for five reasons. First, reducing shipping losses was specifically identified by Congress as the primary purpose of a weather network. Second, one dimension of the distribution of weather information on the Great Lakes is known with great accuracy. That dimension is the number of locations during any fall season, when storms cause the most damage, that offered storm warnings. Third, reasonably reliable data on shipping losses and factors affecting shipping losses are available. Fourth, the geographic placement of the Great Lakes offers an essentially self-contained region in which the stock of ship tonnage is calculated with more confidence than on an ocean coast. And fifth, ships on the Great Lakes are more susceptible to being stranded or thrown ashore than ocean-going vessels. Great Lakes vessels do not have as much open sea in which to navigate during poor weather conditions, and the nature of Great Lakes shipping means that the craft were often near the coastline.

Ships can be damaged in many ways, and not all are weather-related. Ships can sink, collide, become stranded, burn, spring leaks, hit piers, capsize, be blown on the rocks, and have their sails and masts ruined [Chief Signal Officer (hereafter CSO) various years]. An entire cargo can be destroyed with little loss to a ship, just as a vessel can be totally lost with minimal damage to the cargo. Different types of

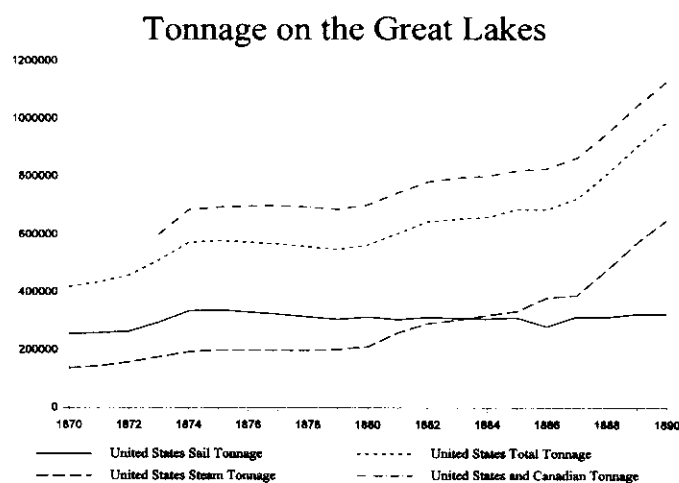
ships are more susceptible to different types of accidents. Steam-powered vessels are more likely to burn on account of on-board propulsion machinery; sailing vessels are more likely to be thrown on the rocks, stranded, or have masts and sails damaged in bad weather.

The Signal Service storm warning network system formally began operation on October 23, 1871 with flag displays at eight ports on the Great Lakes and sixteen ports on the Atlantic Seaboard [CSO 1871, p. 265]. The ports on the Great Lakes at which cautionary signals were displayed initially were Buffalo, Chicago, Cleveland, Detroit, Grand Haven, Milwaukee, Oswego, and Toledo. A cautionary signal was flown "whenever the winds are expected to be as strong as twenty-five miles per hour, and to continue so for several hours, within a radius of one hundred miles from the station." [CSO 1872, p. 573]. In the first year of operation, ending June 1, 1872, 354 cautionary signals were flown on both the Great Lakes and Atlantic Seaboard, approximately 70% of which the Signal Service verified as correctly forecast [CSO 1872, p. 573].

Figure I shows the total United States tonnage on the Great Lakes from 1870 to 1890, its decomposition into sailing and steam craft, and the combined total of United States and Canadian tonnage after 1873¹. The tonnage of United States steam vessels increased rapidly in the late 1880s as iron ore shipments expanded in the Lake Superior region. Anecdotal evidence regarding the increasing efficiency of loading and unloading technology and of fueling facilities for steam vessels suggests that shipping capacity on the Great Lakes grew faster than tonnage capacity. Such technological advances, though, are described as occurring predominantly after the mid 1880s. [U.S. Congress Serial 1431, pp. 9 and 47]. At least in the late 1890s, common judgement held that a steamer could do two and one quarter times the work of a sailing vessel on account of speed [ibid., p. 4]. Sailing vessel tonnage statistics from around

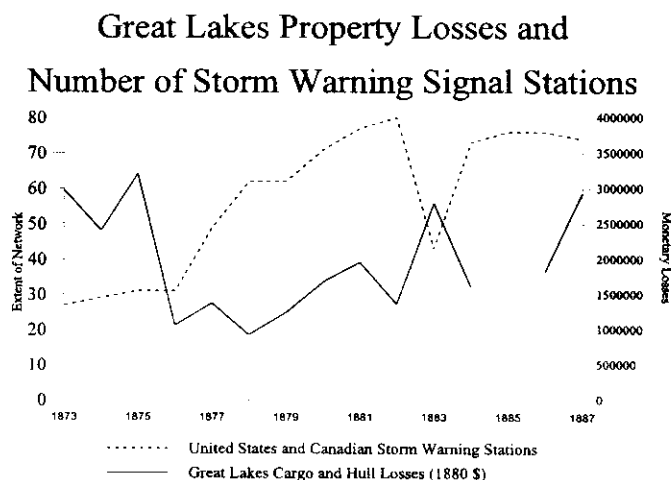
¹ Canal boat tonnage is not included in the figure, as it is not as directly engaged in long hauls on open water where severe weather was a factor. The data begin in 1868, when the United States implemented a new admeasurement system based on internal capacity. I have not reported the first two years as the transition period figures beginning in 1866 are not consistent and suggest the removal of unusually large amounts of obsolete tonnage.

Figure I



Sources: United States Department of Treasury, *Annual List of Merchant Vessels of the United States* (1870-1890); Mansfield, *History of the Great Lakes* (1899).

Figure II



Note: Loss data for 1885 is missing.

Sources: *Chicago Daily Inter Ocean* (December 5, 1874 p. 2; December 18, 1875; December 27, 1876 p. 6; December 17, 1878; December 29, 1879 p. 6; February 3, 1881 p. 12; December 28, 1883 p. 3; December 5, 1885 p. 4) *Marine Record* (December 27, 1883 p. 5; December 25, 1884 pp. 4-5; December 24, 1885 pp. 4-5; December 30, 1886 p. 6; December 15, 1887 pp. 4-5); Chief Signal Officer, *Report of the Chief Signal Officer, 1871-1890*; *Historical Statistics of the United States*, Series E 52-63.

1884 to 1895 are misleading, as "Many of the vessels classed as sailing vessels have really been transformed into barges, for they are now habitually towed." [ibid., p.14]. By the mid 1990s, commercial sailing vessels are said to have disappeared from Lake Superior entirely [ibid.]. The use of iron and steel for hulls does not grow significantly until the early 1880s and comprised only 10% of all steam tonnage in 1885 on the Great Lakes [U.S. Treasury 1885a].

Figure II gives the estimates of monetary losses on the entire Great Lakes, both Canadian and United States, in 1880 dollars, according to the reports of the *Chicago Inter Ocean* and the *Marine Record*. Figure II also shows how the combined number of United States and Canadian storm warning stations changed over time.

The reduction in regular and display storm warning stations in 1883 was due to a decrease in the Signal Service budget . Congress reduced direct weather appropriations after 1882 on account of embezzlement charges against the disbursing officer of the Signal Service [Whitnah 1961, pp. 46-7]. According to General William B. Hazen, the Chief Signal Officer, up to \$237,000 may have been taken by Captain Henry W. Howgate at a rate of \$60,000 per year. With annual Signal Service budgets around \$1 million, Congress might have concluded that service would not suffer after the embezzler's portion of the budget was removed. The variation in the number of stations providing storm warnings offers an unusual opportunity to estimate their effectiveness and value.² Although records indicate precisely which storm-warning locations were closed during the fall of 1883, ship loss records and cargo loss records are not disaggregated enough to observe if the increased losses that season occurred near the ports losing service.³

² One can argue a priori that a storm warning system could be so reliable that captains would leave port under what in the past had been considered marginally dangerous conditions, thereby leading to increased damages with a storm warning system. Increased losses would be a cost outweighed by increased earnings due to greater use of vessels. In the limit, imagine a scenario whereby before weather information was available, there was no shipping commerce due to the high probability of wreck. If most storms are effectively forecast, a shipping industry begins and vessels are lost. This bias implies that analysis of loss data will underestimate the value of storm warnings.

³ There existed two types of storm-warning stations on United States Great Lakes shores. The first type was a Signal Service Station maintained by Signal Service personnel. These stations took observations three times daily yearround and telegraphed the data immediately to Washington, D.C. There were sixteen such stations at

A key feature of my study of weather information on the Great Lakes is that the number of storm warning stations will serve as an independent variable in a regression analysis of Great Lakes shipping losses. The reader might ask if the number of warning stations is an exact measure of the *use* of the storm warning network. In other words, is the number of weather stations an appropriate metric for the amount of weather information provided? For example, shippers may have placed little confidence in the warning service in its early years. The number of storm warning stations in such years along with regression analysis results would then overestimate the real value of the weather information during those years. Ideally, the researcher would estimate how the extent of the distribution of the information combined with the reputation of its reliability produced effective information.

One part of the analysis could specify a loss function based on type one and type two storm forecasting errors with a model of adaptive expectations. One would require information relating the different types of errors to expected costs. Nelson and Winter (1960) show that probability warnings provide more valuable information than binary warnings. In the context of Great Lakes shipping, different types of ships would have found it optimal to remain in port at different levels of warning accuracy. For example, sailing vessels would suffer relatively greater losses from not heeding storm warnings, whereas steam vessels would have a greater opportunity cost of sitting idle in port. In a world with constant weather forecast technology and binary forecasts, the optimal mix of type one and type two forecast errors would change over time as the relative proportion of steam tonnage increased. Given the available data, the construction of such a loss function is excessively ambitious. The forthcoming analysis will assume that the level of effective weather information corresponds in a consistent manner with the number of locations potentially displaying storm signals on the Great Lakes during the fall months. Craft [1995]

major ports and key locations on the Great Lakes in 1883. Nearly all of the storm-warning stations that were closed in 1883 were called display stations and were operated only during the navigation season by civilians. The civilians hoisted storm-warning signals upon receiving telegraphic instructions from Washington, D.C. [Chief Signal Officer various years]. In 1889, the mode cost of paying civilian storm-warning personnel at Great Lakes ports was \$120 per year [Secretary of War 1890]. The costs of a pole, flags, and telegraphic messages were trivial. In other words, the marginal cost of an additional storm-warning location on the Great Lakes was extremely small.

offers data that there existed no clear trend in forecast accuracy.

Optimistic discussion of the newly formed meteorological network in 1871 and explanations of the signals in 1874 in *Barnets Coast Pilot* provide evidence that independent transportation authorities had faith in the benefits of the service from its inception [Barnet 1871, pp. 130-32; 1874, pp. viii and 148]. *Barnets Coast Pilot* was a prominent guide to Great Lakes masters and sailors. It listed, for example, exact sailing directions for standard routes, locations of prominent lights, and navigation rules.

Although the *Annual Report of the Chief Signal Officer* in 1871 records Increase A. Lapham as having telegraphed a storm warning on the Great Lakes on November 8, 1870, his very first day of work, the Chief Signal Officer offers no mention of any other storm warnings until the operation of the system of flag signals began on October 23, 1871 [CSO 1871, pp. 263-65]. Lapham resigned as forecaster on December 26, 1870 for personal reasons [Miller 1931a, p. 69]. Chief Signal Officer General Albert J. Myer appointed Cleveland Abbe assistant to the Chief Signal Officer on January 3, 1871 [Abbe 1909, p. 147]. For months before October of 1871, the Signal office prepared practice synopses showing times and locations of warning signals. The month of October was spent distributing information on the interpretation of the signals which would be displayed with combinations of flags in daylight and lights by night.⁴

The researcher can use at least two strategies to estimate the value of storm warnings on the Great Lakes. A direct analysis studies how vessel and cargo losses change as factors such as a storm warning network, weather, level of commerce, shipping capacity, internal improvements, and technology change. An alternative strategy is indirect and recognizes that the former analysis asks questions similar to those

⁴ In a description of one storm tracked eastward from Omaha beginning on November 11, 1871 and lasting five days, the chronology in the *Annual Report of the Chief Signal Officer* indicates that flag warnings were displayed at all eight Great Lakes ports in the Great Lakes warning network [CSO 1872, pp. 749-50]. The warnings preceded the storm by between five and twenty-two hours at each port. No vessels left the Milwaukee harbor. Some remained in the Chicago port. Some vessels remained at port in Cleveland, while those that put out returned damaged and with loss of life. At least one vessel sank. At Oswego, some craft remained in port while others left. Again, some of those that put out were forced to return in damaged condition, and the storm wrecked one vessel totally. No reports of shipping behavior are recorded from stations in Grand Haven, Toledo, and Detroit.

that insurers and shippers sought to answer when determining insurance rates and shipping rates: "What factors affect a vessel's damages? What is the probability of damage during a specific season? If damaged, what is the distribution of damage amounts?"

III. ANALYSIS OF CARGO AND HULL LOSSES

Although the Board of Lake Underwriters and United States Coast Guard⁵ records provide extensive information on annual losses from 1855 to 1873, the loss data, as well as the tonnage data, are inconsistent. The tonnage classification system changed during the mid-1860s, and the total tonnage by customs districts became available only in 1868. In addition, from 1868 onward, the data allow the subtraction of canal boat tonnage. This is appropriate as canal boats were a significant portion of Great Lakes customs districts' tonnage yet did not venture into open water generally, where storms are a problem. As described above, no weather agency existed before 1870 which could provide objective ex post weather observation data on the severity of storms. Data on Great Lakes commerce are also more limited before 1870. A consistent series of cargo and hull loss data reported by the *Chicago Inter Ocean* and later in conjunction with the Great Lakes trade publication *Marine Record* begins in 1873 and ends in 1887. Loss data for 1885 is missing.⁶

The primary challenge of the analysis is distinguishing the influence of weather information from other factors that could have reduced losses during the same period. Examples of these other factors are: internal improvements, construction of lighthouses, establishment of life-saving stations, and general

⁵ The Coast Guard did not exist during the 1860s, but later presumably came into the possession of records gathered by the Treasury Department's customs houses.

⁶ I have found no evidence that losses during the navigation season of 1885 were particularly high or low. In an era when economists are accustomed to working with enormous data sets, the size of this data set may give pause. Although the data set is small, this observation by itself is no reason to discount the results. Statistical procedures are adjusted for small samples by raising the thresholds at which results are judged to be significant. Results in sections four and five provide additional evidence that estimated coefficients are not the result of random variation.

technological change. Technological change can be manifest in the ships, in the process of recovering damaged ships, and in the loading and unloading ships. One expects improvements in steam-power technology to reduce the probability of ships exploding or burning. Deepening harbors, creating safe harbors on coastlines where no safe ports existed, and deepening critical waterways such as the St. Clair Flats between Lakes Huron and Erie are examples of internal improvements. Holding other factors constant, one hypothesizes that losses will diminish as tonnage capacity rises, because vessels can transport a larger share of the commodities during the safer summer season. Measures of the severity of weather and the level of commerce should have a positive effect on shipping losses. Since steam-powered vessels were generally more valuable, losses should rise as the percentage of lake tonnage that was steam-powered rose.

The above discussion and available data suggest the following multiple regression model

$$\ln(Losses)_t = \beta_0 + \beta_1 GLwarningstations_t + \beta_2 GLweather_t + \beta_3 GLlifestations_t + \beta_4 GLtonnage_t + \beta_5 GLcomprox_t + \beta_6 GLlighthouses_t + \beta_7 GLinternalimp_t + \beta_8 GLpersteamton_t + \beta_9 Trend_t + e_t .$$

Two specification issues suggest that a standard linear regression analysis may be inappropriate. First, as weather information improves and becomes more widely available, the effect of the weather on losses should diminish. In the limit, with perfect weather information and distribution, the coefficient on a severity of weather variable would be zero. Estimation of a semilog specification is the proposed response. This specification gives an untransformed right-hand side variable the following interpretation. Holding all other variables constant, losses are increased or decreased by a constant percentage per unit of the independent variable. In other words, in a year in which losses would be high for other reasons, such as severe weather, a given number of warning stations will be responsible for a larger *absolute* reduction in losses than in an otherwise normal year. Similarly, in a year in which losses are low due to factors such as a wide network of storm warning stations, inclement weather will be responsible for a small *absolute* increase in losses. These interpretations follow directly from the econometric model specification.

Table I

Variables

GLwarningstations	the number of United States Army Signal Service and Canadian Meteorological Service storm warning locations on the Great Lakes in operation during the fall
GLweather	a measure of wind miles over a consistent period at a Great Lakes Army Signal Service weather station
GLlifestations	the number of United States and Canadian Life-Saving Service Stations on the Great Lakes
GLtonnage	Great Lakes tonnage
GLcomprox	a proxy for commerce on the Great Lakes, ⁷
GLlighthouses	a cumulative measure of the number of lighthouses on the Great Lakes
GLinternalimp	a cumulative measure of expenditures on United States Great Lakes internal improvements
GLpersteamton	the percentage of United States Great Lakes tonnage that was steam-powered
Trend	a trend variable

See Appendix A for summary statistics and the correlation matrix.

The second specification issue questions the treatment of weather information as more and more ports were included in the weather network. Recall that the Army Signal Service storm warning network on the Great Lakes ranged in size from zero to fifty-five stations during the years 1870 to 1889. The Signal Service established the first stations at the major ports, and no evidence has been found to indicate that the storm warning network did not expand in a generally optimal manner. Intuition suggests a diminishing marginal effect as the network of stations was extended to more and more ports. The semilog specification implies also a diminishing marginal effect of any right-hand side variables whose coefficient

⁷ The commerce proxy was constructed from information in James David Rae's unpublished dissertation "Great Lakes Commodity Trade, 1850 to 1900" and James Barnett's *Barnett's Coast Pilot*. I calculated millions of cargo ton miles of the following commodities and routes: flour, wheat, corn, and oats from Duluth, Chicago, Milwaukee, and Toledo to Buffalo; iron ore through the St. Mary's Falls Canal (assumed average origin of Octonagon) to Cleveland; lumber to Cleveland, Toledo, Buffalo, and Oswego (assumed origin the Saginaw River); and lumber to Chicago and Milwaukee (assumed origin Manistee). Coal is not included, as it is a return trip from the East. A few missing years in these series had to be interpolated.

is negative.⁸

Alpena, Milwaukee, and Cleveland are the only locations whose wind data is consistent over the period 1873 to 1886. Given its location in northeast Michigan on Lake Huron, it is not surprising that wind at Alpena most successfully explains shipping losses.⁹

No life-saving stations existed on the Great Lakes until 1876, the year the United States Federal government established twenty-nine posts. By 1886, forty-eight Canadian and American stations could be found (Mansfield 1899, 378-80). Although generally equipped and outfitted with apparatus intended to save lives, not property, extensive reports in the various *Annual Report of the Operations of the Life-Saving Service* indicate that keepers and surfmen often assisted stranded boats in getting off rocks and bars and provided relief and support to tug boats rescuing damaged vessels.¹⁰

See Tables II and III for the regression analyses of Great Lakes vessel and cargo losses.¹¹ The coefficients of lighthouse and internal improvement variables are statistically insignificant in all nontrivial specifications. Due to the highly collinear relations among the variables commerce, tonnage, trend, life-saving stations, and percentage of United States tonnage that steam-powered, the interpretation of their individual effects on losses is constrained. Technological changes reducing monetary losses, presumably captured by the trend variable, include better salvage capabilities and new vessel design. The success of

⁸ There does not appear to exist any endogeneity problem in the specification, since new warning stations were established almost invariably before the dangerous fall season began. If there was an endogenous relationship between the severity of weather, level of commerce, and losses on the one hand and the extent of the warning network on the other hand, the coefficient on the value of storm warning locations would be biased downward.

⁹ The variable wind miles is positively correlated with trend, suggesting that the instruments were moved to higher ground between 1873 and 1887. Wind data come from the Weather Service Climatological Record Books.

¹⁰ The Life-Saving Service generously accepted responsibility for saving property each year of an amount equal to the surviving value of any vessels assisted. Such estimates on the Great Lakes for the *fiscal years* 1879, 1880, 1883, and 1884 equaled \$408,970, \$910,556, \$1,510,000, and \$2,145,640, respectively, in 1880 dollars [U.S. Treasury 1879b, 15-16; 1880b 15; 1883b, 16-17; 1884b, 17]. Stonehouse [1994] discusses the Life-Saving Service on the Great Lakes, as well as providing data on the dates of establishment of individual stations.

¹¹ Results differ modestly from Craft [1995] due to more accurate dates of the establishment of the first life-saving stations and the addition of one more data point.

Table II

Semilog Regression Analysis of Great Lakes Shipping Monetary Losses

	Eq. One	Eq. Two	Eq. Three	Eq. Four
Constant	6.1607** (2.8705)	7.3549** (3.333)	6.6992** (2.8457)	9.4371*** (1.3821)
Number of G.L. Warning Stations	-.0116* (.0068)	-.0152** (.0078)	-.0124* (.0068)	-.0155** (.0063)
Total Alpena Wind Movement, Oct.-Nov.	.000229*** (.000075)	.000190** (.000086)	.000258*** (.00007)	.000229*** (.000066)
Number of G.L. Life-Saving Stations	--	--	--	--
Trend	-.2155** (.095)	-.1328 (.1021)	-.1856** (.0914)	-.1176* (.0679)
Percentage of U.S. Tonnage Steam	6.8757** (3.3375)	--	8.2209** (3.1082)	8.5568** (3.1278)
G. L. Tonnage	5.117E-6 (3.691E-6)	6.7053E-6* (4.279E-6)	3.8613E-6 (3.52E-6)	--
Commerce Proxy	.000167 (.000158)	.000292* (.000174)	--	--
Durbin-Watson Stat.	2.90	2.21	3.00	2.90
Rho (AR1)	--	--	--	--
Adjusted R ²	.653	.511	.647	.639

Notes: Losses are in 1880 dollars. The data include the years 1873 through 1887 with 1885 missing. Standard errors are in parentheses.

* Significant at the 10% level of confidence for a one-tailed test.

** Significant at the 5% level of confidence for a one-tailed test.

*** Significant at the 1% level of confidence for a one-tailed test.

Table III

Semilog Regression Analysis of Great Lakes Shipping Monetary Losses

	Eq. Five	Eq. Six	Eq. Seven	Eq. Eight
Constant	6.3675** (2.3958)	12.6885*** (1.0127)	12.2374*** (.9924)	9.1679*** (1.7564)
Number of G.L. Warning Stations	-.0097* (.0063)	-.0162** (.0081)	-.0160* (.0082)	-.0151* (.0083)
Total Alpena Wind Movement, Oct.-Nov.	.000222*** (.000059)	.000164** (.000082)	.000130* (.000090)	.000219*** (.000074)
Number of G.L. Life-Saving Stations	--	-.0255* (.0170)	-.0080 (.0190)	-.0118 (.0122)
Trend	-.2176** (.0755)	--	--	--
Percentage of U.S. Tonnage Steam	8.3487** (3.3473)	--	--	--
G. L. Tonnage	4.4784E-6 (3.754E-6)	--	--	4.555E-6** (2.207E-6)
Commerce Proxy	.000095 (.000151)	--	.000320** (.000150)	--
Durbin-Watson Stat.	2.18	2.38	1.99	2.11
Rho (AR1)	.555* (.346)	--	--	--
Adjusted R ²	--	.472	.461	.458

Notes: Losses are in 1880 dollars. The data include the years 1873 through 1887 with 1885 missing. Standard errors are in parentheses.

* Significant at the 10% level of confidence for a one-tailed test.

** Significant at the 5% level of confidence for a one-tailed test.

*** Significant at the 1% level of confidence for a one-tailed test.

salvage operations seems to have depended on the severity of weather during late fall months. Although United States steam tonnage surpassed sail tonnage in 1884 on the Great Lakes, the percentage of steam-powered vessels constructed with iron ranges only from 8.9% in 1873 to 10.7% in 1886. The average size of sailing vessels increased from 185 tons to 234 tons during the period, while steam vessels increased in size from 227 tons to 299 tons [U.S. Department of Treasury 1873-1890a]. Only in the late 1880s did the size of steam vessels swell dramatically, indicating the growing importance of iron ore transportation. Real expenditures in the United States for harbors of refuge and the broader category internal improvements on the Great Lakes are reasonably smooth during the 1870s and 1880s [Zinn 1915]. The coefficients of lighthouse and internal improvement variables are statistically insignificant in all nontrivial specifications. Presumably, the trend variable captures the influence of all slowly developing factors that lowered losses on the Great Lakes. The inaccuracy of the commerce proxy may result in the implied positive impact of total tonnage on the value Great Lakes cargo and hull losses.

Regression coefficients indicating the value of Great Lakes storm warning locations remain relatively stable as statistically insignificant variables are removed and the specifications are altered. Equation five with a maximum likelihood correction for first order negative serial correlation implies that each additional storm warning location on the Great Lakes decreased losses by just under 1% from what they otherwise would have been.¹² As noted above, this specification also implicitly imbeds the notion of diminishing returns to additional stations into the estimating procedure.¹³ Already by 1872 the largest

¹² Savin and White [1978] find that Durbin-Watson test statistics are still valid in the presence of missing observations, even though the power of alternative tests may be higher.

¹³ The variables in equation five provide the best fit in a standard linear specification as well. The standard and adjusted coefficients of determination are very similar to equations one and five, and the average value for a storm warning station, after correction for autocorrelation, is estimated to be \$20,812. This coefficient is significant at the 10% level for a one-sided hypothesis test. However by 1873, when the data set begins, the largest Great Lakes ports (Alpena, Buffalo, Chicago, Cleveland, Detroit, Duluth, Erie, Escanaba, Grand Haven, Milwaukee, Oswego, Rochester, and Toledo) already had Signal Service stations. A linear specification of the regression equation does not take into account the conjecture that these first few storm warning stations were probably considerably more valuable than the subsequent stations. Consistent data are available beginning only in 1873.

ports on the Great Lakes had Army Signal Service recording and warning stations, thereby causing the above estimating procedure to underestimate the total value of the weather stations, since there was no variation in service to the biggest port cities in the sample.

A point estimate using the semilog specification, however, becomes the median estimate, not the expected value, when the antilogarithm is taken. Given the semilog specification, the expected value of losses with no storm warning system equals the definite integral

$$\int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2} e^y dy$$

where μ corresponds to the semilog specification point estimate.¹⁴

Using equation five's conservative coefficient estimate on the value of storm warning locations, the subtraction of actual losses from the expected losses without a storm warning system yields estimates of savings averaging nearly one million dollars during the early years and rising to between one and four and a half million dollars per year near the end of the period.

As discussed by Craft [1995], false warnings were not rare. Some vessels undoubtedly were delayed by false warnings, especially as winds can be both strong and safe if in the appropriate direction. The preceding discussion excludes the value of shipping time lost due to incorrect forecasts, as well as including reduced wreckage from false warnings keeping vessels in ports. Similarly, I have placed no value on the time savings due to fewer vessels being damaged. In samples of the proportion of monetary losses that were total cargo and total hull losses, the figure is consistently under fifty percent. From 1869 until 1871, 46.5% of losses were total losses of hulls and cargo [United States Coast Guard 1962]. The

¹⁴ In the present context of the exponential function, integrating over all possible values may yield an artificially high value unless the errors in the semilog regression analysis are truly normally distributed. In order to estimate the expected value of lake losses without storm warnings, all integrals are evaluated at limits constructed by 90% mean prediction intervals and then scaled up to reduce the consequences of a non-normal error term.

years at the end of the sample for which the calculation is possible (1884, 1886, 1887, and 1889) average 43.7%. Clearly, if more than half of all losses are only partial losses, many ships spend time in port repairing sails, masts, centerboards, and vessel bodies. These are common damages if one reads a typical list of the season's disasters. I assume that the value of time lost through false storm warnings and the value of reduced wreckage due to false warnings is at least offset by time gained through reductions in the number of damaged vessels. To the extent that some vessels may have left port on occasions when no storm warnings were forecast, but under conditions that prior to the establishment of a weather organization would have restrained captains, the preceding calculations are underestimates of the value of storm warnings.

IV. MARINE INSURANCE

From at least 1855, a well-organized cartel of marine insurers existed on the Great Lakes, known initially as the Board of Lake Underwriters and subsequently as the Inland Lloyds. Minutes of early annual meetings detail explicit plans to survey and classify ships by seaworthiness annually and to station inspectors at strategic locations so that damaged vessels and cargos would be inspected quickly. The Board of Lake Underwriters encouraged cartel rate adherence with the implicit threat of removal of the above reconnaissance service and ship ratings [Board of Lake Underwriters various years].

The existence of a cartel makes the interpretation of insurance premium price data difficult. The more stable the Board of Lake Underwriters insurance cartel was during the 1870s, the more confident one can conclude that changes in insurance prices reflect changes in risk. Strengthening the confidence with which one may use such price data is the fact that, unlike the cost curves for many monopolies or cartels, approximately constant marginal costs in the insurance industry with an assumed linear demand curve imply that changes in marginal costs would lead to smaller adjustments in insurance prices. Under these basic assumptions, any reduction in insurance prices underestimates the reduction in real costs.

Table IV displays cargo insurance rates for grain from Chicago to Buffalo on Class A1 vessels for different seasons as reported publicly by marine insurers. The premium paid is given as a percentage of the value of cargo insured. Note the extreme sensitivity of the price of insurance according to season. Rates drop noticeably from 1862 to the early 1870s and again from the early 1870s to 1879 and 1880. The variance of the seasonality of the rates drops from 1871 to 1873. The increasingly relatively lower rates during the fall seasons after 1871 suggest that insurers may have realized that shipping was safer during these months after the storm warning system began operation in late October 1871.

Newspaper reports during the 1870s and early 1880s record much discussion of the varying effectiveness of the cartel. In 1881, cargo insurers of grain from Chicago to Buffalo began or resumed a pool. An example of the monthly division of risks and premiums is printed in the June 9, 1881 issue of the *Chicago Inter Ocean*. Rebate policies and infrequently reported price quotes constrain the interpretation of insurance rate changes, and quotes for insurance on grain shipments during the period October 1 through October 14 in the years 1880 and 1881 give an indication of the volatility of this insurance market. The rates were 0.60 and 1.50, respectively [*Cleveland Herald* October 4, 1880 and *Chicago Inter Ocean* October 24, 1881, p. 2].¹⁵ Even though the cartel's cohesion may have vacillated over time, cargo insurance rates for September through November dropped in real terms after 1871.

The sources for Table IV are the Board of Lake Underwriters, the Buffalo Board of Trade, and various newspapers. These public sources may not record the market insurance rates perfectly. However, there is no reason to expect, within any year, any inaccuracy in the record of rates to bias the interpretation of rates in favor of finding value in storm warnings. The increase in insurance rates for the summer months during the early 1870s may indicate the waxing of the effectiveness of the insurance cartel. Whether or not this is the case, the reduced seasonal variation in premium rates after 1871 is evidence that

¹⁵ An annual shipment of \$50 million of grain from Chicago to Buffalo combined with an average .3 cent premium (risk) reduction per \$100 insured implies approximate social savings of \$150,000 per year. Section V provides data on the distribution of grain shipments throughout the navigation season.

Table IV

Great Lakes Grain Insurance Premiums from Chicago to Buffalo
(cents per \$100 insured)

	1862	1871	1872	1873	1879	1880
April	1.52	0.315	0.99	1.08	.33-.20	.20-.10
May	0.95	0.27	0.90	0.56	n.a.	n.a.
June	0.95	0.27	0.36	0.56	n.a.	n.a.
July	0.95	0.27	0.36	0.56	0.225	n.a.
August	0.95	0.36	0.36	0.56	n.a.	n.a.
September 1-14	1.14	0.45	0.756	0.756	0.45	0.35
September 15-30	1.52	0.675	1.08	1.08	0.45	n.a.
October 1-14	1.71	1.575	1.404	1.404	n.a.	0.60
October 15-30	2.09	2.025	1.62	1.62	n.a.	n.a.
November 1-14	2.66	2.70	2.16	2.16	1.25	1.00
November 15-30	3.42	3.60	n.a.	2.70	1.25	n.a.

Sources: Board of Lake Underwriters, *Report of the Eighth Annual Meeting of the Board of Lake Underwriters*, 1862, pp. 26-29; Buffalo Board of Trade, *Statistics and Information Relative to the Trade and Commerce of Buffalo* 1872, 1873, and 1874, pp. 35, 38, and 35, respectively; *Chicago Inter Ocean* (July 3, p. 6; September 1, p. 6; and 10, p. 7; November 1, p. 6; and 15, p. 7, 1879; April 9, April 21, and November 2, 1880); *Detroit Free Press* (September 26, 1879); *Cleveland Herald* (March 25, 1879; September 7 and October 4, 1880).

the relative risk of delivery of grain from Chicago to Buffalo during the fall months, when weather factors endangered ships most often, diminished substantially.

Recall the reduction in storm warning locations on the Great Lakes during the fall of 1883. One might presume that cargo insurance rates would rise. Large cities, however, such as Chicago, Detroit, and Buffalo, did not lose their storm-warning service. Since grain-laden vessels would not be expected to stop at smaller ports enroute between Chicago and Buffalo, the changing risk level in the fall of 1883 can not be confirmed with data on cargo insurance between Chicago and Buffalo.¹⁶

¹⁶ I have not been able to recover any cargo insurance rates from 1883.

V. GRAIN SHIPMENTS FROM CHICAGO TO BUFFALO

This section uses Chicago Board of Trade statistics on weekly shipping prices and monthly shipping levels of grain from Chicago to Buffalo to investigate the value of weather information. If storm forecasts proved valuable to lake shippers, one expects the price of shipping grain from Chicago to Buffalo to diminish. But it is also true that other factors could be expected to have lowered shipping costs during the 1870s. Improved dock and ship technology, as well as increased competition from railroads, could be expected to lower the price of shipping grain from Chicago to Buffalo.

See Figures III and IV for data on the level, timing, nominal prices, and price differentials of shipping wheat, oats, and corn by sail from Buffalo to Chicago.¹⁷ The fall is defined as September, October, and November; the summer as May, June, July, and August.¹⁸ The Chicago Board of Trade recorded lake shipments by commodity by month and the price of grain shipments by week. I constructed weighted averages of prices by taking the average corn shipping price per bushel for a month and weighting it by the shipments of corn, wheat, and oats for that month. Figures III and IV indicate at most weak relationships among the factors amount of grain shipped per calendar year, the portion shipped during the fall months, and the summer-fall price differential. Both figures show, however, that the absolute level and the percentage premium of the summer-fall price differential falls over time, especially after 1872 and 1873, the first two years of full fall operation of the Army Signal Service's storm warning system.

Consider first the hypothetical effect on shipping prices of doubling the capacity of vessels by increasing the number of trips per year from better dock technology. If we assume all dock and operating

¹⁷ The portion of grain shipments from Chicago by sail is not available. Anecdotal evidence suggests that steam vessels carried larger and larger portions, beginning sometime during the early 1880s. The practice of steam vessels towing sail vessels became more and more common in the early 1880s. Sail and steam cargo rates did rise and fall together.

¹⁸ Some grain was also shipped in April. The amount depended on the timing of the opening of the Straights of Mackinac, in addition to the size of the crop to be transported.

Figure III

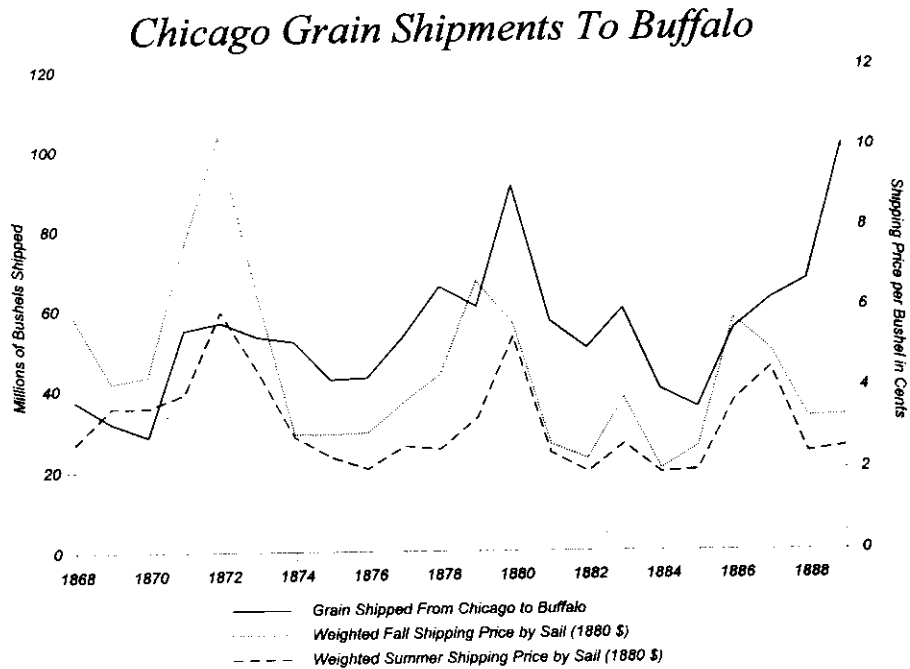
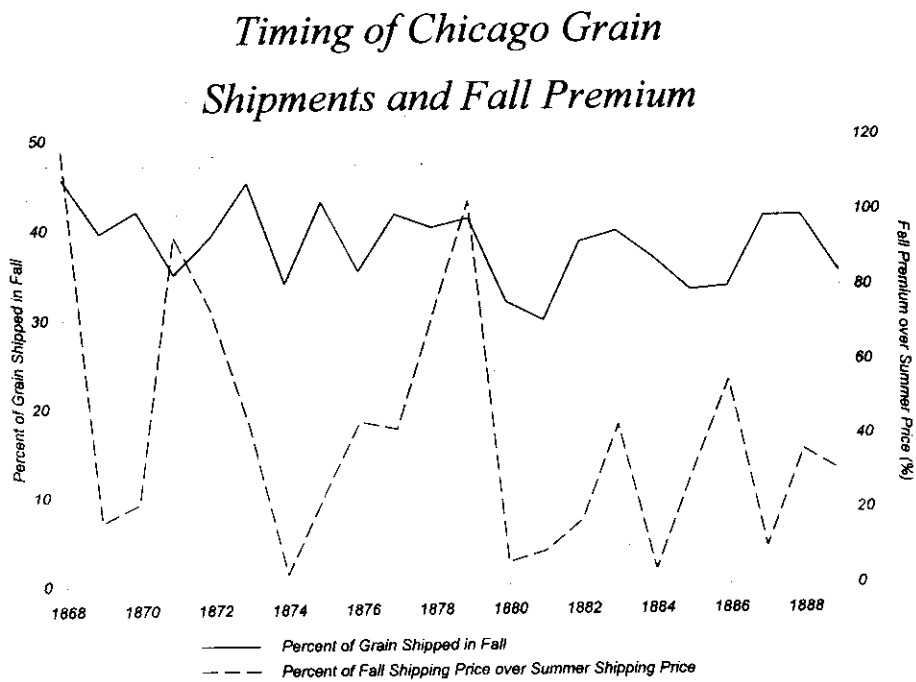


Figure IV



Sources: Chicago Board of Trade, *Statement of the Trade and Commerce of Chicago, 1868-1889*; *Historical Statistics of the United States*, Series E 52-63.

costs remain constant and storms do not cause shipping damage during the summer months, summer shipping prices would fall by fifty percent before reaching a new equilibrium. Fall shipping prices would fall by a lower absolute amount because damages due to storms would rise. Improved loading and unloading technology could be expected then to increase the absolute summer-fall price differential, as well as the percentage fall premium. Similar logic holds for increased capacity and efficiency of ships due to size and speed, if safety is unaffected by marginal increases in the size of sailing vessels.¹⁹ The creation of deeper channels permits the use of larger vessels. Other internal improvements such as improved lighting of dangerous passageways and the construction of safe harbors will lower shipping costs, but the affect on the summer-fall price differential is uncertain.

Alternatively, imagine all technology except storm forecasting remaining constant on the Great Lakes. Since severe storms are much rarer during summer months, storm warnings would have a correspondingly greater effect on the fall shipping price.²⁰ Under reasonable assumptions, storm warnings should lead to greater percentage decreases in fall shipping rates than summer rates.²¹ The data in Figure III and Figure IV show that the average fall percentage premium drops from 61% during the period 1868 to 1873 to 33% over the years 1874 to 1889. As argued above, other identifiable factors such as improvements in loading and unloading technology and increased capacity and efficiency of ships imply an

¹⁹ The average size of sailing vessels on the Great Lakes increased from 156 tons in 1870 to 209 tons in 1880 to 258 tons in 1890 [U.S. Congress 1898, p. 12]. For steam vessels, the average size was 223 tons in 1870, 228 tons in 1880, 286 tons in 1885, and 427 tons in 1890 [U.S. Treasury 1870-1890a]. The average tonnage data for steam-powered vessels includes tug boats.

²⁰ See Eichenlaub's *Weather and Climate of the Great Lakes Region*.

²¹ Assume weather-related costs entail four percent of expected summer costs but thirty percent of expected fall costs and that other costs are identical for both the fall and summer seasons. By reducing expected weather damages by one half on account of forecasts and assuming all other costs are identical, the ratio of costs falls from 1.25 to 1.13.

increased fall premium, *ceteris paribus*.²²

VI. Social Rate of Return

If one calculates a minimum bound on the value of weather information without explicitly including human lives, one must show that loss of human life did not increase with the advent of storm warnings on the Great Lakes. Signal Service reports [CSO 1875-1881] record an average one hundred forty-five lives lost per year due to Great Lakes disasters for the years 1874 to 1876. The figure drops to one hundred for the period 1877 to 1881. Annual newspaper accounts from seven years in the 1860s yield an average of one hundred seventy-three lives lost each year on vessel disasters.²³

Craft [1995] presents an overview of the Army Signal Service weather service during its first twenty years with specific emphasis on its storm warning service on the Great Lakes. He reports annual budgets of the entire Signal Service for those years during which Army personnel resources were explicitly included in the Federal budget. He estimates the resource costs during the remaining years by using data on direct weather appropriations and assuming similar ratios of costs as exist in the complete budgets. He also lists the expenditures of the Canadian Meteorological Service. By 1880, combined United States and Canadian meteorological service budgets stabilized at about one million dollars. In addition, Craft estimates the annual costs of a weather network of equal forecast accuracy solely designed for the Great Lakes.

In any particular year, the calculated savings in reduced losses to vessels and cargo may be quite plausible, whereas the sum of all the reductions in losses over many years is, in general, not an accurate

²² One can estimate a general magnitude of potential savings by multiplying a 28% savings in fall premium times the average summer shipping rate times the annual bushels shipped times the portion of grain transported in the fall. This calculation, which is only illustrative, gives an approximate figure of \$140,000 savings per year for grain shipments from Chicago to Buffalo. Combined with cargo insurance savings, the estimate of the value of storm warnings to shippers of grain from Chicago to Buffalo is nearly \$300,000 in a typical year.

²³ See Craft [1995].

measure of the social value of reduced transportation costs on the Great Lakes. If vessel owners know or expect weather information to lower the probability of damage to their property or the property they transport, the existence of a storm warning system lowers the expected cost of transportation on the Great Lakes. A lower equilibrium cost of transportation services implies a higher equilibrium quantity. Safer passage on the Great Lakes increases the level of commerce on the Great Lakes.

Therefore, when one seeks to calculate the social rate of return to the creation of a storm warning system on the Great Lakes, avoided losses are the relevant benefits to be summed. Assuming an infinitely elastic transportation services supply curve, these benefits correspond to the increased consumer surplus resulting from lowered transportation costs. The standard linear approximation for estimating the first order effects of the welfare loss if storm warnings did not exist is given by the formula

$$\text{Lost Consumer Surplus} = P_1 X_1 \tau (1 - \frac{1}{2} \tau \eta) \quad ,$$

where P_1 and X_1 are, respectively, the initial price and quantity of transportation services on the Great Lakes, τ is the percentage price increase in transportation services resulting from the removal of storm warnings, and η is the absolute value of the price elasticity of demand for transportation services.

In effect, Section III estimated $P_1 X_1 \tau$ (a rectangle) as the value of storm warnings on the Great Lakes for each year, so a conservative estimate of the social value of the weather service requires the removal of the value $(1/2)P_1 X_1 \tau \eta$ (a triangle) from each year's estimated savings. Assuming an elasticity of demand for transportation services equal to -1.0 and a ten percent increase in transportation services' costs in the absence of weather information implies a five percent downward correction to the estimates in Section III. If the elasticity of supply of transportation services is less than infinite, it can be shown that the preceding correction exceeds the correct adjustment, thereby leading to an underestimate of the value of weather information.

Given the preceding adjustments, the 1880 present value of weather expenditures and loss

reductions is calculated using a four percent nominal interest rate which approximates the rate of return on high quality bonds during the 1870s and 1880s [Homer 1963, pp. 309-16]. The estimated minimum bound on the social rate of return to all weather information expenditures of the United States Army Signal Service and Canadian Meteorological Service from 1870 through the first half of fiscal year 1888 is 68 percent.²⁴ When estimating the cost of a weather network solely designed for the Great Lakes, the corresponding minimum rate of return rises to 402 percent.²⁵ These estimated rates of return include neither the value of weather information on the Atlantic seaboard nor in any other context in the United States or Canada other than transportation on the Great Lakes from 1873 to 1887. Note that the estimated savings due to storm warnings also do not include any of the reduced shipping losses in either the fall of 1871 or 1872. The Signal Service already operated the warning system in the largest ports on the Great Lakes during this time, but the absence of consistent data on losses, wind miles, and Great Lakes tonnage prevents the inclusion of these years in the rate of return calculations.

VII. Conclusion

Three distinct empirical data sources have offered evidence that the Army storm warning service during the 1870s and 1880s on the Great Lakes provided valuable information to shippers. Rough estimates of both the savings due shippers on account of reduced insurance premiums paid (or risk born) and the decreased fall grain cargo premium for grain leaving Chicago are consistent with annual Great Lakes cargo and hull loss reductions ranging from one to four and one half million dollars, depending on the year. Early Federal weather information services were a valuable investment which provided a high

²⁴ The corresponding rate of return calculation for the linear specification using the same variables as equation five is 9 percent. This is a priori an underestimate of the value of weather information on the Great Lakes, as no variation of weather services at the largest ports occurs in the sample data. Alternatively, had the semilog estimates in equation four been corrected for autocorrelation and used in the present value discounting procedure, the minimum social rate of return calculation would yield 109 percent.

²⁵ See Craft [1995] for the derivation of costs for a Great Lakes weather network of equal forecast accuracy.

social rate of return, even ignoring reduced shipping losses on the Atlantic Seaboard and all other uses of the Canadian and United States national weather networks. The marginal storm warning display station reduced Great Lakes cargo and hull losses by approximately one percent in any given year.

Future research will attempt to characterize and estimate the social value of ex post weather information as it encourages the consumption-smoothing of weather-sensitive commodities. In 1881, the Army Signal Service organized a special daily cotton region reporting system which collected temperature and precipitation data from a dense network of observers and reported it to the nation's cotton exchanges. The development of this service and its effect on the contemporary cotton market may offer insight into the use and value of publically released information.

Appendix A

DESCRIPTIVE STATISTICS

	Mean	Std. Dev.	Min.	Max
Value of Great Lakes Cargo and Tonnage Losses (1880 dollars)	1900735	777662	929670	3212966
Number of Great Lakes Warning Stations	57.4	20.2	27	80
Total Alpena Wind Miles October - November	14022	1306	12260	16180
Number of Great Lakes Life-Saving Stations	29.5	18.2	0	54
Percentage United States Great Lakes Tonnage Steam-powered	.415	.077	.337	.554
Great Lakes Tonnage	737,340	71,429	599,300	860,900
Commerce Proxy	4564	1006	3228	6857

Note: The annual data correspond to the years 1873-1887 with loss data missing in 1885.

CORRELATION MATRIX

	GLWS	WIND	GLLS	TREND	PER-STEAM	GLTON	COM-PROX
GLWS	1.00						
WIND	0.43	1.00					
GLLS	0.86	0.36	1.00				
TREND	0.82	0.38	0.95	1.00			
PERSTEAM	0.70	0.30	0.85	0.95	1.00		
GLTON	0.68	0.24	0.85	0.95	0.93	1.00	
COMPROX	0.83	0.74	0.79	0.84	0.83	0.74	1.00

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