May 1994

Bursting Boilers and the Federal Power Redux: The Evolution of Safety on the Western Rivers

Richard N. Langlois
University of Connecticut

David J. Denault

Samson M. Kimenyi
University of Connecticut

University of Connecticut

Department of Economics Working Paper Series

Bursting Boilers and the Federal Power Redux The Evolution of Safety on the Western Rivers

Richard N. Langlois
University of Connecticut

David J. Denault
University of Macedonia

Samson M. Kimenyi
University of Connecticut

Working Paper 1994-01

May 1994

---

341 Mansfield Road, Unit 1063
Storrs, CT 06269–1063
Phone: (860) 486–3022
Fax: (860) 486–4463
http://www.econ.uconn.edu/

Abstract

Using newly constructed data series on explosions, deaths, and steamboat traffic, we examine econometrically the causes of increased safety in steamboat boilers in the nineteenth century. Although the law of 1852 (but not that of 1838) did have a dramatic initial effect in reducing explosions, that reduction came against the background not of a system out of control but of a system that from the beginning was steadily increasing boiler safety per person- mile. The role of the federal government in conducting and disseminating basic research on boiler technology may have been more significant for increased safety than its explicit regulatory efforts.

Introduction.

The harmful side-effects of modern technology are a popular subject for newspaper headlines and television news magazines — from automobile crashes and airline disasters to industrial catastrophes like the one a few years ago in Bophal, India. Moreover, some forms of technological side-effects (notably those arising from toxic substances like asbestos) are beginning to strain present-day regulatory structures — a strain often described as a “crisis” for the legal system and the insurance industry. But the harmful effects of technology are not a new phenomenon: they have been with us as long as technology has. And the modern regulatory system was not created overnight; it grew out of a long history of institutions aimed at controlling harms — not only government institutions but also legal and market ones.

This paper attempt to illuminate the present-day issues by going back to the history of one particular 19th-century area of technological harms: steamboat boiler explosions. Indeed, it was the problem of boiler explosions on steamboats that led to the first instance of federal safety regulation (in 1838[1] and again in 1852[2]), which in turn served as a precedent for the government’s more extensive subsequent interventions into private markets.

---

1 5 *U. S. Statutes at Large* 305 (1838).

2. 10 *U. S. Statutes at Large*. 10 (1852).

In "Bursting Boilers and the Federal Power," historian of technology John G. Burke (1966)[3] offered a kind of Whig history of how the federal government started down the path of safety regulation. In his account, a failed "unregulated" system in the early nineteenth century gave way to increasingly enlightened federal safety regulation. The pressure of a public outcry over the loss of life — by Hunter's (1949) estimate some 3,270 persons in the whole U.S. between 1816 and 1848 — coupled with the united efforts of the "scientifically and technically knowledgeable members of society" led to the slow demise of an ideology in which "the enlightened self-interest of an entrepreneur sufficed to guarantee public safety" (Burke 1966, pp. 3 and 2). In Burke's view, this ideological change was thrust upon a reluctant country by the exigencies of modern technology.

This essay looks at a small piece of the story, namely the unexamined contention that the "unregulated" system was failing in a way that falsified contemporary anti-interventionist presumptions. Using newly constructed data series on explosions, deaths, and steamboat traffic (both tonnage and person-miles traveled), we examine econometrically the causes of increased safety in steamboat boilers. Our conclusion is that, although the law of 1852 (but not that of 1838) did have a dramatic initial effect in reducing explosions, that reduction came against the background not of a system out

3. A similar and partially complementary analysis is Bartrip's (1980) discussion of the regulation of stationary boilers in Great Britain. On the American case see also Brown (1989).

of control but of a system that from the beginning was steadily increasing boiler safety per person-mile. In the end, we suggest, the role of the federal government in conducting and disseminating basic research on boiler technology may have been more significant for increased safety than its explicit regulatory efforts.

Steamboat Explosions and Safety.

As with any historical data, it is difficult to get accurate figures on steamboat explosions and the deaths they caused. Modern accounts of the boiler safety issue — including Hunter (1949), Burke (1966) and Brown (1989) — rely on only contemporary newspaper accounts and government reports of explosions. Recently, however, Denault (1993) has supplemented and corrected these data using authoritative directories, notably the "Losses of United States Merchant Steam Vessels, 1790-1868" in Lytle-Holdcamper (1975) and the accounts of western-river steamboats in Way (1983).

To determine the safety of steamboat travel, however, one needs to know not only the number of deaths from explosions but also the number of person-miles traveled. Hunter (1949, p. 521) lamented that "[l]ack of information on mileage and number of passengers makes it impossible to fix the hazards of steamboat travel in terms even roughly comparable to data on travel hazards by present-day modes of transportation." Since Hunter wrote, however, Haites, Mak, and Walton (1975) and Haites and Mak (1978) have constructed estimates of tonnage and people (passenger + crew) miles. Denault (1993) has updated these estimates using a newer edition of Lytle-Holdcamper (1975). Table 1 sets out these estimates. They illustrate a dramatic increase over the period in the volume of river transportation.

Year	Tonnage	Passenger miles (million)	Crew miles (million)	Year	Tonnage	Passenger miles (million)	Crew miles (million)
1825	11419	30.6	19.7	1843	84552	568.1	278.4
1826	15913	46.4	29.0	1844	94002	637.6	316.1
1827	19521	59.4	37.3	1845	98489	689.9	341.1
1828	19567	61.8	39.7	1846	108722	777.3	379.2
1829	22590	77.1	48.0	1847	124119	917.1	437.5
1830	25158	61.8	39.7	1848	135127	1042.7	486.5
1831	29414	109.9	69.0	1849	131137	1032.0	480.3
1832	36817	140.2	90.3	1850	136610	1115.9	508.4
1833	38488	157.9	99.6	1851	146264	1239.5	552.3
1834	43099	182.0	116.9	1852	160736	1420.0	615.5
1835	52305	261.0	147.6	1853	176613	1607.9	686.7
1836	59048	300.1	170.5	1854	176451	1635.0	697.7
1837	66931	354.6	197.2	1855	179157	1699.4	719.6
1838	69405	385.4	208.4	1856	194169	1839.1	780.0
1839	82040	454.0	252.4	1857	208617	1976.4	838.1
1840	86312	497.7	270.3	1858	205293	1944.8	824.7
1841	87856	525.4	280.5	1859	202498	1911.4	814.0
1842	79622	496.1	258.7	1860	206800	1945.6	831.8

Table 1.

Tonnage, passenger mileage, and crew mileage, 1825-1860
Source: Denault (1993), appendices B and E.

Table 2 combines estimates of steamboat explosions and fatalities with the data for person-miles.

Year	Explosions	Deaths
1825	.07952	.59642
1826	.06631	.15915
1827	.03102	.04137
1828	.02956	.31527
1829	.01599	.07994
1830	.10094	1.15074
1831	.01118	.06708
1832	.00868	.01735
1833	.02330	.33010
1834	.02007	.09702
1835	.02203	.24474
1836	.02550	.19975
1837	.02175	.23378
1838	.02358	.47491
1839	.00991	.10476
1840	.00911	.05859
1841	.00620	.03847
1842	.01457	.13911
1843	.01063	.07206
1844	.00944	.05243
1845	.01261	.08147
1846	.00519	.04496
1847	.01107	.11516
1848	.01112	.08436
1849	.00661	.08332
1850	.00985	.15761
1851	.00558	.08371
1852	.00786	.11692
1853	.00218	.00436
1854	.00429	.04887
1855	.00289	.02150
1856	.00115	.00764
1857	.00142	.01279
1858	.00181	.03539
1859	.00257	.05027
1860	.00216	.03997

Table 2.

Explosions and deaths per million person-miles, 1825-1860
Source: Denault (1993), Table 11, p. 183.

Year	Deaths
1923-27	.1820
1928-32	.1560
1933-37	.1555
1943-47	.1052
1957	.0598
1967	.0550
1977	.0335
1987	.0263

Table 3

Automobile deaths per million vehicle miles, selected years .
Source: National Safety Council, *Accident Facts 1990* .

These estimates permit us in fact to make some rough comparisons with modern modes of transportation. Table 3 presents estimates of automobile safety for selected years. The numbers aren't fully comparable, as the automobile data are in terms of vehicle-miles rather than passenger miles. But it is clear that steamboat safety (at least with respect to boiler safety)[4] was of the same order magnitude as that of automobile travel for most of the twentieth century. Also, the fatality rate for railroads in 1900 was 0.057 deaths per million passenger miles (U. S. Interstate Commerce Commission 1900).[5] And there is reason to think that stagecoaches and

4 These figures do not include accidents from snags, fires, and other non-explosion hazards.

5 This figure overestimates the safety of railroads, as it excludes employee deaths, which exceeded passenger deaths by ten to one.

ocean-going vessels were considerably more dangerous than contemporary steamboats (Denault 1993, p. 93). Needless to say, of course, it was public perception of risk rather than actual relative safety that is significant for the origins of regulation. As Hunter (1949, p. 522) put it, what "aroused public opinion and moved legislative bodies was less the cold calculation of total losses and relative risks than the shock of individual disasters which did not occur at an exotic distance, but frequently at one's doorstep." Indeed, the bias of the spectacular[6] is still with us: as McKenzie (1991, pp. 76-78) points out, the public believed airline safety to have been declining in the 1980s even though it was actually improving.

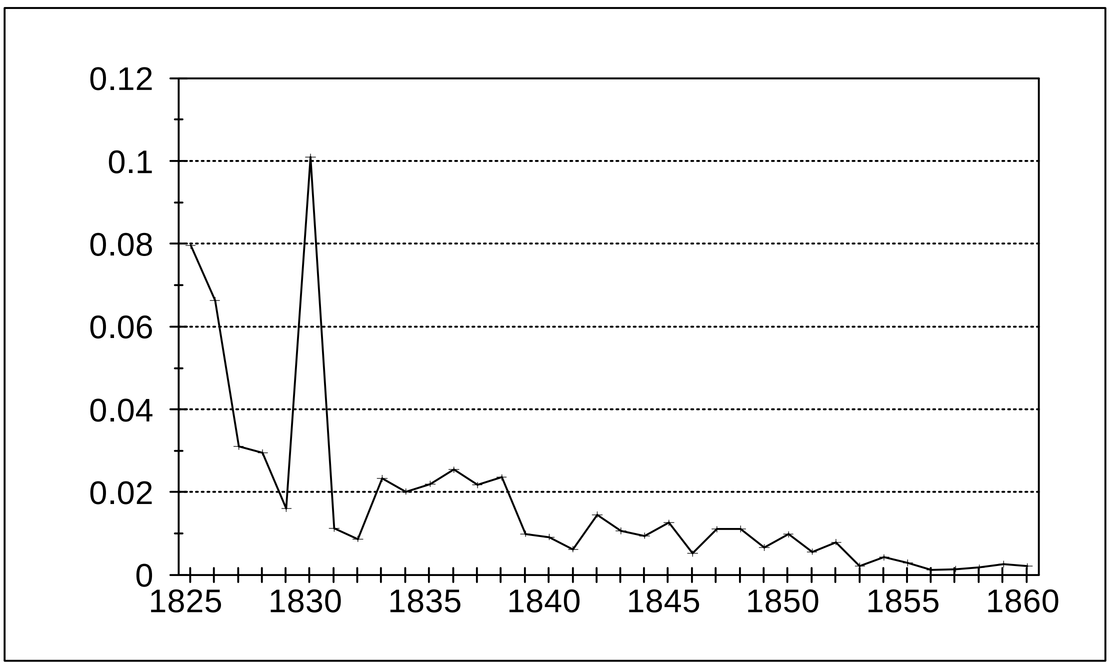

Figure 1
Explosions per million person-miles, 1825-1860

---

6 A form of what cognitive psychologists and decision theorists would call availability bias. See for example

Figures 1 and 2 present in graphical form the data on explosions and fatalities per person-mile over the period 1825-1860. We analyze these data more formally below. But it is clear from these figures that the overall trend was toward greater safety, and this trend was pronounced well before federal regulation. Figure three presents the data for deaths per million person-miles in semi-log form, which makes the trend show up more visibly.

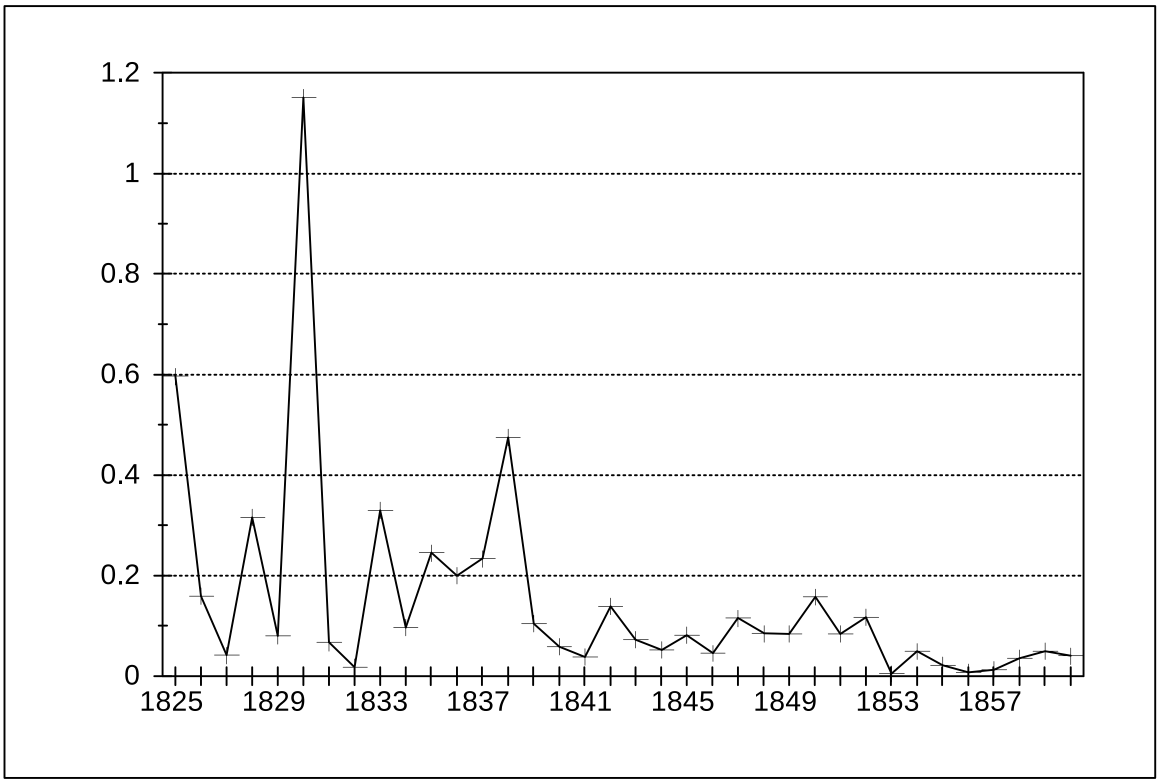

Figure 2

Deaths per million person-miles, 1825-1860

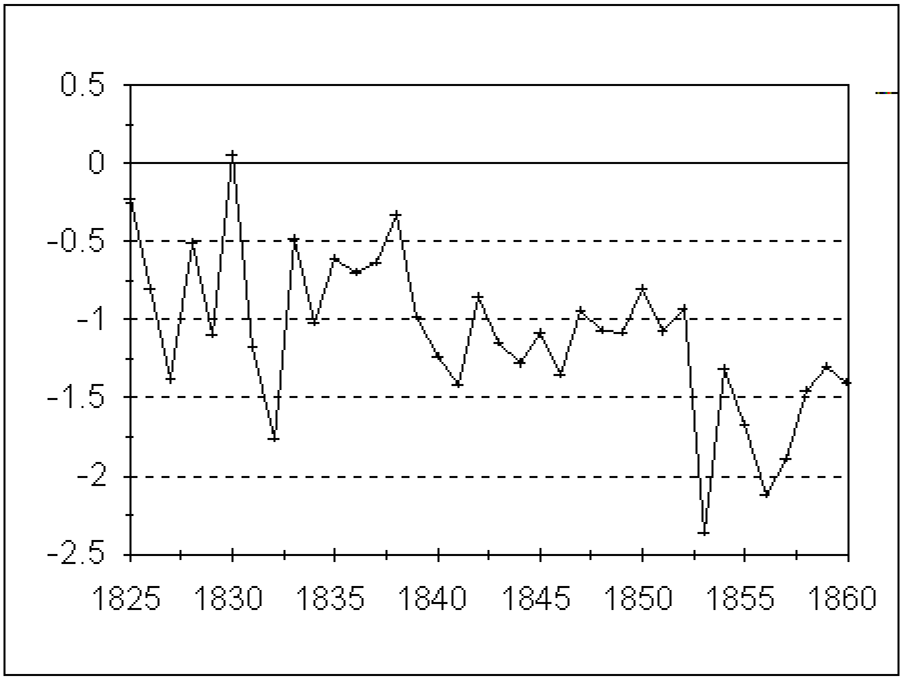

Figure 3

Log of deaths per million person-miles, 1825-1860

What caused boiler safety?

If one agrees that the overall trend in western river steamboat travel was toward greater safety, the obvious question becomes: what led to that greater safety. We place the possibilities under three headings: Technological change; organizational change; and government regulation.

Technological change.

By technological change we mean the gradual improvement in both machinery and techniques of practice. These had two principal sources: the incremental, empirical, groping evolution of technology and practice that came from the legion of boilermakers, shipbuilders, captains, and engineers, and the more scientific, if no less empirical, knowledge of abstract boiler design and the physics of steam developed by researchers at the Franklin Institute and elsewhere.

As Hunter (1949, p. 121) notes, the history of steamboat engine design and construction

> is one of plodding progress in which inventions in the formal sense counted far less than a multitude of minor improvements, adjustments, and adaptations. The heroes of the piece were ... the anonymous and unheroic craftsmen, shop foremen, and master mechanics in whose hands rested the daily job of making things go and making them go a little better. The story of the evolution of steamboat machinery in the end resolves itself in large part into such seemingly small matters as, for instance, machining a shaft to hundredths rather than sixteenths of an inch, or devising a cylinder packing which would increase the effective pressure a few pounds, or altering the design of a boiler so that cleaning could be accomplished in three hours instead of six and would be necessary only every other instead of every trip.

This "plodding progress" was aided by the fact that a dominant design of a steamboat engine set in early. Once a dominant design is established, it permits technological change to proceed steadily and incrementally.[7] In steamboats, the dominant design consisted of a simple, high-pressure, horizontal steam engine fed by a battery of cylindrical boilers. The engines were crude by the standards of stationary boilers or the low-pressure boilers

[7] On which, for example, see Utterback (1994).

more typical on east-coast steamboats.[8] But they were extremely well adapted to an environment in which fuel was in relatively abundant supply and capital and skill in relatively short supply. “At the close of the thirties,” as Hunter (1949, p. 139) notes, “this engine had reached, in its essential features, its fully developed form.” The trajectory of technological development thereafter was toward more power. Two engines driving independent paddle wheels became common, with a typical battery of up to seven boilers, each some 32 feet long and 42 inches in diameter. Each boiler contained two internal flues and had a firebox at one end. It was made of wrought iron (with cast iron heads in the early years) of one-quarter inch in thickness, and was riveted together with the joints staggered for greater strength.

Technological change also brought slow improvement in safety equipment.[9] In the years just before the passage of the regulations of 1852, a number of key safety technologies came into widespread use. Glass tube gauges became practicable around 1850 with the development of an alkali-free glass that would resist clouding up under the effects of steam. These

---

8 It is not obviously the case, however, that, as many contemporaries believed, high-pressure boilers were more dangerous than low-pressure boilers. In the period before 1932, in fact, there were more injuries from explosions of (largely eastern) lower-pressure boilers than from explosions of high-pressure boilers. See Committee on Steamboats *Report*, May 18, 1932 (U. S. House of Representatives Document 478, ser. 228 [Washington: 22d Congress, 1st session]).

9 This paragraph draws on Denault (1993), chapter IV.

replaced the try-cock gauges that had been in universal use since 1843.[10] About the same time, wrought iron replaced cast iron for boiler heads as problems of suitably forming the wrought iron were solved. Most importantly, perhaps, the years before 1852 saw the widespread adoption of "doctor pumps," so called because they cured the ills of steam boilers. One of the principal facts about steamboat boiler explosions is that they occurred overwhelmingly at or near docks. The reason was that steamboats would typically continue to generate steam while stopped to pick up or discharge passengers or freight. This obviated recreating a head of steam at each stop and thus saved valuable time. Before the doctor pump, however, the pumps feeding water to the boilers ran off the main drive shaft and would cease to operate while the boat was stopped. As a consequence, water levels could become dangerously low, exposing metal to the fires and thus weakening the boiler.[11] The doctor pump allowed water to be fed to the boilers even when the boat was docked.

Advances in scientific knowledge — or, at any rate, more abstract technological knowledge — also contributed to increased safety, even if the diffusion of that knowledge was a slow process. Already by the 1820s, there

---

10 It is true, however, that the act of 1852, which required steam gauges, accelerated their adoption. Between 1850 and 1860, some 30 patents for steam gauges were awarded, in contrast with almost no patents before that time (Hunter 1949, p. 164).

11 As we will see, contemporary practitioners were remarkably ignorant about the theoretical causes of boiler explosions, and this explanation was unknown to them, even though the empirical relationship between low water and explosions was well known.

was much concern voiced in government over the problems of steamboat boiler explosions. In 1830 — by far the most dangerous year in our sample — the destruction of the Helen McGregor near Memphis took some 60 lives and galvanized the federal government to action. Although it stopped short of adopting any regulation, the House instructed Treasury Secretary Samuel D. Ingham to investigate and report on boiler accidents. In what is considered the first federal grant for scientific research (Dupree 1957, p. 50), Ingham provided funds to the Franklin Institute of Philadelphia, founded six years earlier to promote the mechanical arts and applied science, to conduct a study. Between 1831 and 1836, an Institute team headed by Alexander Dallas Bache, a professor of natural philosophy at Penn, conducted careful experiments of various kinds, even to the point of blowing up test boilers in a quarry outside Philadelphia.

> The group's findings overturned a current myth, proving conclusively that water did not decompose into hydrogen and oxygen inside the boiler, with the former gas exploding at some high temperature. The experimenters demonstrated that an explosion could occur without a sudden increase in of pressure. Another widely held theory they disproved was that when water was injected into a boiler filled with hot and unsaturated steam, it flashed into an extremely high-pressure vapor, which caused the boiler to rupture. The group proved that the reverse was true: the larger the quantity of water thus introduced, the greater the decrease in the steam pressure (Burke 1966, p. 13).

The team also made suggestions about the inadequacy of test cock gauges, the use of fusible alloys, and the quality of wrought iron.

Although the Franklin Institute study influenced Congress in what eventually became the safety act of 1838, the report was not widely known among practitioners on the rivers, and was in fact printed in only 500 copies in addition to its publications serially *in The Journal of the Franklin Institute* (Denault 1993, p. 115). It is, moreover, clear, as evidenced in the debates surrounding proposed reforms of the 1838 act, that confusion continued to reign about the causes of boiler explosions. In 1848, Edmund Burke, the Commissioner of Patents, undertook another study of the causes of boiler explosions. His report featured long abstracts of the Franklin Institute Study, by then ten years old. Burke's report was issued in 1849, with a printing of 10,000 copies. The year 1849 is thus arguably a watershed in popular understanding of the abstract properties of steam, the causes of boiler explosions, and the basics of sound boiler design and maintenance.

Organizational issues.

In contemporary debates over boiler safety, technological issues shared the spotlight with — and often took a back seat to — issues of what would nowadays be called human factors. The problem, many argued, was not so much that well-managed boilers were dangerous but rather that boilers were often incompetently managed.

Especially in the early years, steamboat captains were often boat owners or (more typically) part owners, and, as a consequence, were often less experienced in steamboat operation than were their subordinates.[12] The main complaint against captains was racing, a legendary but perhaps debatable cause of boiler explosions. It was to the engineer, however, that the finger of blame most often pointed. Whereas river piloting was already a well-developed skill (among keelboatmen and bargemen) at the beginning of the steam era, the steamboat owners could draw on no similar pool of knowledgeable steam engineers. With the rapid growth of western river steam, this class of worker always remained in short supply, and it is difficult to underestimate the amount of criticism directed at the abilities and character of engineers. These men served apprenticeships as short as three months, and, as we have seen, possessed little genuine knowledge of steam operation. They were often accused of negligence, drunkenness, and — that worst of all nineteenth-century faults — possessing an inferior character.

But the skill and behavior of the crew members were certainly under the control of the steamboat owners to some extent. Economists would no doubt insist that owners would invest in training and supervision if the cost of doing so outweighed the benefits. These costs and benefits, in turn, depend on the "governance structures"[13] under which the steamboat was organized. In the early years, it was common for steamboats to be owned by consortia of five or more owners. These included merchants, steamboat

12 The actual steering and navigation of the boat was entrusted to the pilot, who, by all accounts, was typically highly skilled and conscientious. Hunter (1949, pp. 240 ff.).

13 A term from Williamson (1985).

builders, and others with local knowledge of river transport who would integrate forward or backward into boat ownership. Limited liability joint-stock companies were not common until the very end of our period, so most of the steamboats were owned either as associations of part owners or partnerships (Hunter 1949, p. 311). It is interesting, however, that the trend throughout our period was for ownership to become concentrated. As Table 4 suggests, ownership by groups of more than five owners declined while single proprietorships increased. (Ownership by two to four persons remained relatively constant.) A simple model of management and ownership[14] would suggest that increased concentration of ownership in a pre-corporate world would reduce the costs and increase the marginal benefits of training and monitoring, leading to increased boiler safety.

	1 Owner		**2-4 Owners**		**5 or More**		**Corporate Ownership**	
Year	Number	Tonnage	Number	Tonnage	Number	Tonnage	Number	Tonnage
1830	18.9	14.9	56.8	55.0	24.3	30.1	—	—
1840	17.3	19.6	51.2	48.2	31.5	32.2	—	—
1860	27.4	25.2	51.8	52.3	14.3	15.3	6.5	7.2

Table 4
Steamboat ownership, 1830, 1840, 1860 (in percent).
Source: Hunter (1949, p. 311).

14 Along the lines suggested by Alchian and Demsetz (1972), for example.

Regulation.[15]

The early history of federal debates over boiler regulation is a history of Congressional reaction to spectacular steamboat explosions. In 1824, the Aetna exploded in New York harbor, killing 13 persons. A bill was promptly introduce in the House calling for an inquiry into the possibility of outlawing high-pressure boilers,[16] but the bill died soon after being reported out of committee. As we saw, the Helen McGregor disaster in 1830 prompted the funding of the Franklin Institute study as well as legislation in 1832 that would have required federally funded inspections and would have outlawed building steam without adequate water supply while a boat was stopped. The legislation did not pass.

In general, early proponents of regulation tended to be Whigs, and opponents, citing the sanctity of property rights granted by the Constitution, tended to be Democrats. Nonetheless, Democratic Presidents Jackson and Van Buren supported legislation,[17] and on Van Buren's urging the Senate passed a bill in early 1838. It was, however, the disaster of the *Moselle* near Cincinnati, which killed 151 in April of that year, that galvanized the House into action. The resulting statute — the first federal safety regulation —

---

15 This section draws on Hunter (1949, chapter 13), Burke (1966), and Denault (1993, chapter VIII).

16 Unlike most eastern steamboats, the *Aetna* used high-pressure boilers, which were the technology of choice on the western rivers.

17 The Democrats, however, tended to favor *ex post* and non-adminsitrative measures, as typicfied by the provision in the 1838 statute that made the fact of a boiler explosion *prima facie* evidence of negligence in tort.

created a rather toothless inspection system and made some changes in tort and criminal law as an attempted deterrent to negligence.

Inspectors under the 1838 statute were appointed by local federal judges. They were required to inspect boilers semiannually, but the law provided no criteria for such inspection. The boat owners were to pay $5 for each inspection, which was the inspector's sole source of income. As one might expect, inspections under this system were often perfunctory when not fraudulent, and, indeed, even thorough visual inspections not complemented by hydrostatic testing were essentially useless. The law also made boat owners clearly liable for damages, made employees liable to manslaughter changes in the cases of negligent death, and made the fact of an explosion *prima facie* evidence of negligence. For a number of reasons, however, including contemporary attitudes toward lawsuits and the typical judgment-proofness of impecunious steamboat owners, few suits were ever brought.[18]

Dissatisfaction with the 1838 statute began almost as soon as the ink was dry. In 1852, Congress passed the second boiler safety statute. Even though most of the bills opponents were Democrats, the legislation enjoyed bi-partisan support — perhaps a testimony to changing attitudes toward government interference with private property right. Interestingly, although east-coast ship owners tended to oppose legislation, western ship owners

[18] For a thorough analysis of legal cases and doctrine, see Denault (1993), chapter VII.

wanted the inspection system changed so that, among other things, the government and not the owners themselves would pay for the inspections. The 1852 statute did just this, setting up the federal Steamboat Inspection Service.[19] Inspectors were given broad discretion to order changes at any time, and were required to test boilers hydrostatically each year at one and one-half times working pressure, which could in no case exceed 110 psi. Inspectors were also empowered to license engineers and pilots.[20] In addition, the law required safety valves — one in a locked case to prevent tampering — and the provision of adequate feed water. And it required that boilers be constructed of iron plate stamped according to quality. At the urging of owners, the law removed the provision of the 1838 statute making an explosion *prima facie* evidence of negligence, even despite the lack of suits and despite the strict standards to which owners would have been held in any case under common law.

Regression results.

In order to explore more formally the evolution of safety over time and the effectiveness of the federal safety acts of 1838 and 1852, we regressed the log of both explosions and deaths per million person miles against time, and we

---

19 In fact, the new inspection system did not supersede the old, which continued to apply for many years to boats not carrying passengers.

20 Steamboat owners and other businessmen pushed for this provision as well (Hunter 1949, p. 538), possibly as a way to shift some of the costs of training and selection onto the government and the engineers themselves and/or to solve a prisoners' dilemma problem by eliminating the incentive to hire unqualified engineers.

introduced dummy variables for the regulations of 1838 and 1852. The results of the OLS model are shown in table 5.

	Explosions	Deaths
Intercept	-18.857**	-24.802*
	(-2.85)	(-1.96)
TIME	-0.176***	-0.190**
	(-4.069)	(-2.304)
LAGE	1.747	3.52
	(1.22)	(1.29)
LFLTWT	4.129**	5.848
	(2.21)	(1.64)
REG52	-1.049***	-1.755***
	(-3.37)	(-2.96)
R^2	0.882	0.43

Notes: t-statistics in parenthesis. R^2 is the adjusted coefficient of multiple determination. Asterisks denote significance at the 1 percent (***), 5 percent (**), and 1 percent (*) levels.

Table 5
OLS regression results.

The variables LAGE and LFLTWT deserve comment. LAGE is the log of the average age of the western steamboat fleet. We use it as a proxy for the age of the boilers in use on western waters. The average age of the fleet ranged from a low of 3.14 years in 1832 to 3.51 years in 1860. In general, the average age of the fleet increased over time. Keeping in mind the general increase in speed and days running per year, this means that over time boilers ran for longer periods in a given year and for more years than did their predecessors. We thus expected the age variable capture the “vintage” effect of using older boilers. In both the explosion and deaths equations, however, this variable has the expected positive sign, but it is not statistically significant.

The variable FLTWGT, the log of the weighted average of people loads, is a proxy for congestion on steamboats, which both increased in size over time (allowing them to carry more people per trip) and began to carry more passengers on a per-ton basis. Such congestion should reduce safety per million people miles. Curiously, perhaps, this variable is significant and has the expected sign in the explosion equation, but it is not significant in the deaths equation.

REG52 is a dummy variable, set to one in years 1853-1860, that attempts to proxy the effect of the regulation of 1852. It is clearly significant, with the expected negative sign, in both equations. (We used a similar dummy for the 1838 regulation. It was never significant, and we do not even bother to report the model including it.)

Given the kind of data we have here, an alternative estimation procedure would be to use a model appropriate for “count” data. That is, because the observations on the number of explosions and deaths are non-negative integers, an appropriate approach is one that uses a statistical framework based on a discrete probability distribution. One such statistical framework is the Poisson model.

The loglikelihood function of the Poisson model is specified as

$$\log(f) = y^* \log(b) - b\text{-}\log(y),$$

where y is the dependent variable (explosions or deaths), and b is a linear function of the various explanatory variables. The signs of the coefficients (positive or negative) imply that increases in the explanatory variable increase or decrease the expected value of the dependent variable (explosions or deaths). The maximum-likelihood results of the Poisson model are reported in Table 6. As in the OLS model, the results show that the 1852 legislation had a negative and statistically significant effect on the number of explosions and deaths.

	Explosions	**Deaths**
Intercept	-0.0390	-1.578
	(-0.846)	(-1.05)
TIME	-0.00358	0.0561
	(-0.314)	(1.51)
$TIME^2$	-0.00149 ***	-0.0293***
	(-4.18)	(-2.49)
Age	0.0443	-0.0748
	(0.317)	(-0.174)
FLTWGT	0.116***	0.0881***
	(13.10)	(2.85)
REG52	-1.631***	-1.080***
	(-20.12)	(-3.74)
Log-likelihood		

Notes: t-statistics in parenthesis. Asterisks denote significance at the 1 percent (***), 5 percent (**), and 1 percent (*) levels.

Table 6
The Poisson model.

In order to make more precise the connection between the significance of this dummy and the regulation, we tried the OLS version of the explosions model with dummies in alternate years — 1850, 1848, 1854, and 1856. The dummies for years before 1852 were not significant. The dummies for years after 1852 were significant, but not significant at as high a level as the 1852 dummy.

	Model 1	Model 2	Model 3	Model 4
Intercept	-14.730*	-6.811*	-11.889	-8.343
	(-1.73)	(-0.84)	(-1.79)	(-1.33)
TIME	-0.162***	-0.131**	-0.145***	-0.126***
	(-3.13)	(-2.63)	(-3.182)	(-2.78)
LAGE	1.935	1.719	1.778	1.684
	(1.19)	(1.03)	(1.13)	(1.07)
LFLTWT	2.928	0.742	2.144	1.150
	(1.23)	(0.32)	(1.15)	(1.76)
D1850	-0.556			
	(-1.35)			
D1848		0.034		
		(0.084)		
D1854			-0.632**	
			(-2.03)	
D1856				-0.60**
				(-1.97)
R^2	0.771	0.757	0.786	0.784

Notes: t-statistics in parenthesis. R^2 is the adjusted coefficient of multiple determination. Asterisks denote significance at the 1 percent (***), 5 percent (**), and 1 percent (*) levels.

Table 6
Alternate dummy variables

In using the binary variable REG52, we are assuming that the slope coefficients are the same for the pre- and post-legislation periods and that the regulation affects the intercept only. This is not necessarily so, however, and the slope coefficients could have been different for the two periods. We use a Chow test to evaluate whether the two samples (before legislation and after legislation) are structurally different. To perform a Chow test of the hypothesis that all coefficients specified in the equations are equal for the inspection and non-inspection periods, it is necessary to estimate the coefficients for each model for both periods as well as for the entire period. One records the sum of squared residuals (SSR), the degrees of freedom (df), and the number of explanatory variables (k), and then computes the F statistic and compares it with the critical value as given in a statistical table. If the computed F value is greater than critical value of the F-distribution, the null hypothesis that the coefficients for the two periods are equal is rejected. We use the following regression results to perform the Chow test:

```
1825-1860

LEXMI = -0.559 - 0.096TIME + 1.192 LAGE - 0.229 LFLWGT
       (-0.109) (-2.159)     (0.773)     (-0.177)

k=4 N1= 36  df= 31  SSR1 = 7.936

1825-1851

LEXMI = -12.54 - 0.148 TIME + 0.720 LAGE + 0.355 LFLWGT
        (-1.874) (-3.080)    (0.504)      (1.609)

k=4 N2=27  df = 22 SSR2 = 4.61

1852-1860

LEXMI = 53.49 - 0.166 TIME  + 10.92 LAGE  - 15.044 LFTWGT
       (2.599)  (-1.750)     (2.536)       (-2.723)

k= 4 N3= 9 df= 4 SSR3 = 0.50
```

$$F = \frac{[SSR1 - (SSR2 + SSR3)]/k}{(SSR2 + SSR3)/[(N2 + N3) - 2k]}$$

$$= \frac{[7.938 - [4.61 - 0.500]/4}{(4.61 + 0.50)/[(27 + 9) - 2*8]} = 5.31$$

The critical F statistic for 4 explanatory variables and 28 degrees of freedom is 2.71, at the 95 percent level of confidence. The table value is less than the computed value, and therefore we must reject the null hypothesis that the coefficients from the two periods are equal.

The results of the Chow test suggest that there were changes that occurred during the period after the safety act was put in place that affected the slope coefficients. Although this doesn't rule out the possibility that the change in regime arose from factors other than the regulation, it certainly fails to disconfirm the significance of the 1852 legislation.

We are thus left with an overall downward trend in explosions and deaths per million person-miles — a trend arguably attributable to technological and organizational change in steamboating, coupled with a shift after 1852 that was likely the result of safety legislation and (especially) the hydrostatic tests it required. We can thus ask the following question. What would have been the number of deaths and explosions during the inspection period if we assume that the slope coefficients did not change? To answer the question, we use the estimated coefficients for the pre-inspection period to compute what would have been the expected values of explosions per million person-miles during the post inspection period. We can then compare the computed with the actual values of explosions per mile. The comparisons helps determine what the number of explosions per mile would have been in absence of the regulation or other changes.

Table 7 reports the actual explosions and the expected explosions per million person-miles for the period 1853 to 1860. In all cases, the expected explosions per mile assuming the pre-inspection coefficients are higher than the actual explosions. Thus, although there would have been a consistent decline in the number of explosions per million person-miles in the absence of the regulation, it appears that the regulation did play an important role in reducing the number of explosions.

Year	Actual (with regulation)	Expected (no regulation)
1853	0.00218	0.00950
1854	0.00476	0.00812
1855	0.00289	0.00750
1856	0.00127	0.00636
1857	0.00142	0.00573
1858	0.00180	0.00558
1859	0.00256	0.00490
1860	0.00216	0.00373

Table 7

Projected and actual explosions per million person-miles 1853-1860.

Bibliography.

Bartrip, Peter W. J. 1980. "The State and the Steam-Boiler in Nineteenth-Century Britain," *International Review of Social History* **25**: 77-105.

Brown, John K. 1989. *Limbs on the Levee: Steamboat Explosions and the Origins of Federal Public Welfare Regulation, 1817-1852*. Middlebourne, WV: International Steamboat Society.

Burke, John G. 1966. "Bursting Boilers and the Federal Power," *Technology and Culture* **7**(1): 1-23.

Denault, David J. 1993. *An Economic Analysis of Steamboat Boiler Explosions in the Nineteenth-Century United States.* Unpublished Ph.D. Dissertation, the University of Connecticut.

Douglas, Mary, and Aaron Wildavsky. 1982. *Risk and Culture.* Berkeley: University of California Press.

Dupree, A. Hunter. 1957. *Science in the Federal Government*. Cambridge:

Haites, Erik F., James Mak and Gary M. Walton. 1975. *Western River Transportation: the Era of Early Internal Development, 1810-1860.* Baltimore: John Hopkins University Press.

Higgs, Robert. 1987. *Crisis and Leviathan*. New York: Oxford University Press.

Hunter, Louis C. 1949. *Steamboats on the Western Rivers: An Economic and Technological History.* Cambridge: Harvard University Press.

Tversky, Amos, and Daniel Kahneman. 1981. "The Framing of Decisions and the Psychology of Choice," *Science* **211**: 453.

U. S. Interstate Commerce Commission. 1900. "Report of the Interstate Commerce Commission," in *Statistics of Railways in the United States.* Washington, DC: Government Printing Office.