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US Water Pollution Regulation over the Past Half Century: Burning Waters to Crystal Springs?

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In 1969, the Cuyahoga River in Cleveland, Ohio, lit on fire. Historically, this fire was unremarkable—rivers in Baltimore, Detroit, Buffalo, Philadelphia, and elsewhere caught fire throughout the nineteenth and early twentieth centuries, and the Cuyahoga had lit on fire at least 13 previous times since 1868 (Adler 2002). But the event attracted enormous attention. A widely read *Time* magazine article (*Time* 1969) noted:

> The Potomac reaches the nation's capital as a pleasant stream, and leaves it stinking from the 240 million gallons of wastes that are flushed into it daily. Among other horrors, while Omaha's meat packers fill the Missouri River with animal grease balls as big as oranges, St. Louis takes its drinking water from the muddy lower Missouri because the Mississippi is far filthier. . . . Among the worst of them all is the 80-mile-long Cuyahoga . . . No Visible Life. Some river! Chocolate-brown, oily, bubbling with subsurface gases, it oozes rather than flows. "Anyone who falls into the Cuyahoga does not drown," Cleveland's citizens joke grimly. "He decays."

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Outrage at the 1969 fire is often listed as one reason behind the passage of US environmental laws in the early 1970s (Adler 2002; Dingell 2010).

The Cuyahoga has not burned since 1969 and today is home to 40 species of fish (National Park Service 2018). But water pollution issues are not just a part of history. Today, over half of US rivers and lakes violate environmental standards, and 4 to 28 percent of Americans in a typical year receive drinking water from systems that violate health-based standards (Allaire, Wu, and Lall 2018; Environmental Protection Agency 2018a). Flint, Michigan, recently exposed 100,000 residents to dangerous levels of lead in drinking water. Contaminated drinking water leads an estimated 16 million Americans to suffer from gastrointestinal illness annually (Messner et al. 2006).

Polls also suggest that water pollution has been Americans' top environmental concern for at least 30 years (Gallup 2018). Figure 1 shows the percentage of respondents to an annual US Gallup poll who say they are concerned a "great deal" about various environmental problems. Approximately 60 percent of Americans today list both drinking water pollution and river and lake pollution as a great concern. In every survey since 1989, the share concerned about each of these issues has substantially exceeded the shares expressing concern about air pollution, climate change, and other environmental problems (Gallup 2018).

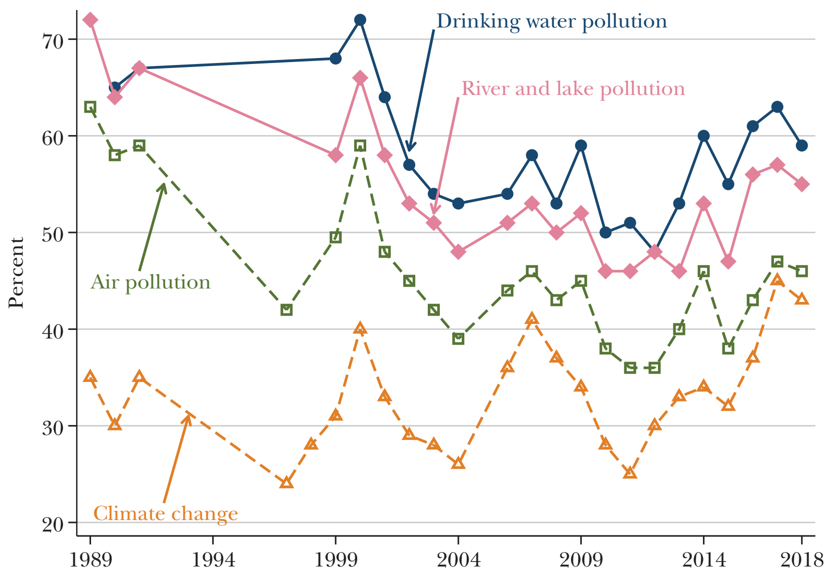
The federal government sought to address these concerns with three actions: it created the Environmental Protection Agency (EPA) in 1970, the Clean Water Act in 1972, and the Safe Drinking Water Act in 1974. The Clean Water Act regulates "surface waters"—rivers, lakes, and some ocean areas. Whether the Clean Water Act regulates groundwater, which includes subsurface aquifers, is legally disputed (Brownhill and Rosen 2018). The Safe Drinking Water Act regulates drinking water, which includes groundwater or surface water that is purified by a drinking water treatment plant and then transported by pipe to households and businesses.

A half century later, these laws still manage US surface and drinking water. Since 1970, the United States has spent approximately \$4.8 trillion (in 2017 dollars) to clean up surface water pollution and provide clean drinking water, or over \$400 annually for every American.[1] In the average year, this accounts for 0.8 percent of GDP, making clean water arguably the most expensive environmental investment in US history. For comparison, the average American spends \$60 annually on bottled water (Arthur 2018).

This article is structured around four main questions: What forces led to these laws? How do they regulate pollution? How effective and efficient have they been? Why has recent economic research focused relatively little on water pollution, and what can remedy this lack of research?[2] We will also illustrate that water pollution

[1] For the calculations behind this estimate, see online Appendix B, available with this article at the *Journal of Economic Perspectives* website.
[2] Other economic reviews of water pollution appear in Freeman (2000), Olmstead (2010), Griffiths et al. (2012), and Fisher-Vanden and Olmstead (2013).

Figure 1
Share of Americans Concerned "A Great Deal" about Various Environmental Issues, 1989–2018



Source: Gallup (2018).
Note: Each poll asks, "I'm going to read you a list of environmental problems. As I read each one, please tell me if you personally worry about this problem a great deal, a fair amount, only a little or not at all." The graph shows four issues to avoid too many lines obscuring the main patterns. Results for other issues, which are not surveyed in all years, include the following: loss of tropical rain forests (mean share 40 percent), extinction of plant and animal species (38 percent), contamination of soil and water by toxic waste (54 percent), damage to Earth's ozone layer (42 percent), acid rain (28 percent), loss of natural habitat for wildlife (51 percent), ocean and beach pollution (51 percent), maintenance of the nation's fresh water for household needs (48 percent), and contamination of soil and water by radioactivity from nuclear facilities (49 percent). Stated concern about drinking water and stated concern about river and lake pollution equal or exceed stated concern about each of these other issues in nearly every year of the survey.

provides an excellent setting to learn about externalities, cost-benefit analysis, local public goods, fiscal federalism, regulatory design, nonmarket valuation, and other classic economic issues. Indeed, water pollution is a textbook example of an externality—at least since Stigler (1952, 1966), introductory texts have used the example of a plant dumping waste in a river and causing people downstream to suffer to illustrate the concept of externalities.

We emphasize four conclusions. First, many measures of drinking and surface water pollution have fallen since the founding of the Environmental Protection Agency, due at least in part to the Clean Water Act and the Safe Drinking Water Act. The progress, however, is incomplete. As William Ruckelshaus, first head of the EPA, summarized: "Even if all of our waters are not swimmable or fishable, at least they are not flammable" (as quoted in Mehan 2010). Second, these large investments could be more cost effective—they could achieve the same aggregate pollution reduction at lower cost, by better utilizing market-based instruments, regulating agriculture, and exploiting returns to scale in drinking water treatment. Third, most analyses estimate that the benefits of existing regulations of surface water quality are *less* than their costs, which is not the case for most government regulations. We highlight several reasons why existing studies may underestimate the true value of surface water quality. Fourth, relatively little economic research focuses on water pollution and its regulation, especially relative to research on air pollution. We suggest some reasons for this lack of research.

What Forces Led to the Clean Water Act and Safe Drinking Water Act?

Human health provided the most common historic rationale for public policy to improve water quality. Sanskrit texts from 4,000 years ago describe purification methods for drinking water that are still used today. Roman bureaucrats under Augustus Caesar sought to eliminate lead piping since it was "hurtful to the human system" (Raucher 1996). For centuries, typhoid and cholera caused a large number of deaths. John Snow's (1855) famed study of London, which provided early evidence that water transmitted cholera, is sometimes considered the founding of modern epidemiology and quasi-experimental research. In the early twentieth century, many cities began chlorinating and filtering drinking water, and cholera and typhoid rates plummeted (Cutler and Miller 2005; Alsan and Goldin 2019). By the 1950s, these investments had nearly eliminated US cholera and typhoid epidemics, and so weakened the health-based rationale for additional investment.

The federal government did create some drinking water standards in the early twentieth century, but before the 1970s, the federal government had largely left water quality up to cities and states. Their water pollution policies and enforcement were limited: as of 1969, only 59 percent of drinking water systems met the preexisting federal standards (Public Health Service 1970). For surface waters, the federal laws before the Clean Water Act of 1972 also had limited power. A 1948 law included regulations that Congress described as "almost unenforceable," and President Dwight Eisenhower called water pollution a "uniquely local blight." Regulators summarized, "The solution to pollution is dilution" (Milazzo 2006). After one of the earlier Cuyahoga River fires, for example, Cleveland prohibited refineries from discharging oil into the Cuyahoga, but violation of this ordinance was punished only with a rarely applied $10 fine (Adler 2002).

The environmental movement helped change this inattention to water pollution. Demonstrations for the first Earth Day in 1970 included 20 million people—among the largest demonstrations in US history.

Along with the 1969 Cuyahoga River fire, other proximate causes of the environmental movement include the production of many new industrial chemicals, photographs of Earth taken from space, and a major 1969 oil spill off the coast of Santa Barbara, California. In 1973, a study found dozens of chemicals, including potential carcinogens, in the drinking water of New Orleans and Pittsburgh (Raucher 1996). New Orleans area residents at the time described drinking water supplies as smelling "oily-petrochemical" and fish from the nearby Mississippi River as unsalable due to "oily" or "chemical" tastes (Environmental Protection Agency 1972; Agee 1975). Deeper causes of the environmental movement at this time may have included broader social activism and rising national incomes.

Several aspects of politics from the 1950s and 1960s affected water pollution policy in the 1972 Clean Water Act and beyond. First, discussions of surface water pollution had little reference to health; indeed, the Clean Water Act is perhaps the only major environmental regulation of the 1970s and 1980s that does not have health as a main goal (Cropper and Oates 1992). Second, because industry opposed regulation of water pollution, policymakers focused on subsidies to wastewater treatment plants rather than industrial regulation. Third, to assuage concerns that southern states were attracting manufacturing with weak regulation, policymakers created uniform national standards. Finally, to ensure political support from rural representatives, investment in reducing water pollution disproportionately targeted small towns (Milazzo 2006). Water quality policy at that time also largely ignored agriculture.

How Do These Laws Regulate Pollution?

Clean Water Act

The general goals of the 1972 Clean Water Act were implausibly ambitious: eliminating discharge of *all* pollutants into navigable waters by 1985, making *all* water safe for fishing and swimming by 1983, and prohibiting *all* discharge of toxic amounts of toxic pollutants.[3] President Nixon vetoed the Clean Water Act, due to costs that he called "unconscionable" and "budget-wrecking," but bipartisan majorities voted to override the veto in the Senate (52–12, with 36 senators not voting) and the House (247–23, with 1 "present" and 160 abstentions) (*CQ Almanac* 1972).

The Clean Water Act had two main activities. The first provided grants to cities to improve wastewater treatment plants. In most cities, underground pipes transmit polluted water from homes and businesses to a plant that abates pollution before discharging treated wastes to surface waters. The United States has around 15,000 such plants. The federal government allocated grant funding across states according to formulas considering state population, forecast population, and wastewater treatment needs (Congressional Budget Office 1985). Within a state, grants were allocated according to an annual "priority list." These grants began in 1957 under predecessor laws to the Clean Water Act, but their scale increased after 1972. In total, the federal government provided around 35,000 grants. Projects funded by these grants between 1960 and 2005 cost about $870 billion over their lifetimes (in 2017 dollars)—about $230 billion in federal grant funds, $110 billion in municipal matching funds, and

[3] Technically the 1972 law was called the Federal Water Pollution Control Act Amendments of 1972. We follow common practice in referring to it as the Clean Water Act.

$530 billion in operation and maintenance costs.[4] In 1987, the grants program transitioned to a subsidized loan program, the Clean Water State Revolving Fund. The second main policy involved permits distributed to facilities discharging pollution from a fixed source (like a pipe) into navigable surface waters—the National Pollution Discharge Elimination System. Each permit describes the levels of pollution the plant may discharge. These permits focus on five conventional pollutants (for example, bacteria such as fecal coliform) and 126 "priority" toxic pollutants, though they may cover other water quality measures (Environmental Protection Agency 2010).

It may be informative to compare the Clean Water Act with water quality policies in other countries. Many countries have subsidized municipal investment in wastewater treatment plants, including Brazil, Canada, France, India, Japan, New Zealand, and South Korea, and many countries set standards to regulate industrial pollution emissions. Other aspects of regulation, however, differ substantially between countries. Canada's 1970 Canada Water Act focuses on supporting partnerships between Canada's federal and provincial governments, on product standards, and on research; the US Clean Water Act focuses less on these topics (Booth and Quinn 1995). The year 2000 EU Water Framework Directive has limited enforcement provisions but centralizes most regulatory decisions in the European Commission (whereas the Clean Water Act decentralizes many decisions to states) and regulates groundwater (Craig 2018). Agricultural runoff and non-point-source pollution remain top water quality problems in many industrialized countries, though farm management and training in some countries may help (Parris 2011).

The focus of the Clean Water Act on wastewater treatment and point-source emissions has led to less focus on other water pollution concerns. Here, we mention several such issues.

The Clean Water Act largely ignores agricultural pollution, which contributes to some of the worst surface water quality problems (Craig and Roberts 2015). These problems include a "Dead Zone" in the Gulf of Mexico where oxygen shortages kill much aquatic life. The Clean Water Act does regulate large and some medium-sized animal feedlots ("concentrated animal feeding operations"). Initially, the Clean Water Act ignored agricultural pollution because it was not perceived as an important issue and because it was more difficult to monitor abatement and emissions. Agricultural water pollution abatement typically involves management practices, such as the timing and method of applying fertilizer and its relationship to soil conditions. Agricultural pollution abatement also involves land use decisions, which the US federal system generally reserves as a power for states (Malik, Larson, and Ribaudo 1994). The federal government does operate some farm management programs pertinent to pollution, but these programs are voluntary and have low funding (Keiser, Kling, and Shapiro 2019).

Another challenge involves the language of the Clean Water Act protecting "Waters of the United States," which has led to legal debates over how this term

[4] For details, see online Appendix B.

applies to roughly half of US waters, primarily composed of wetlands, headwaters, and intermittent streams. Two Supreme Court decisions held that the Clean Water Act does not protect most of these waters (*Rapanos v. United States*, 547 US 715 [2006]; *Solid Waste Agency of Northern Cook County (SWANCC) v. US Army Corps of Engineers*, 531 US 159 [2001]). In 2015, the Obama administration issued the Waters of the United States Rule, which sought to reinstate these protections. However, in 2017, President Trump issued an executive order to rescind or revise this rule. The net benefits of these regulations have also become controversial (Boyle, Kotchen, and Smith 2017).

An additional challenge is the rise of fracking (more properly, hydraulic fracturing), which has increased US gas and oil production but has also raised concerns of contaminating groundwater and surface waters. Fracking extracts natural gas or crude oil from underground shale rock, typically by combining horizontal drilling with the high-pressure injection of water, chemicals, and sand. The corresponding concerns for water quality involve chemicals leaking from wells, improper cement casing around the well, and improper storage of fracking liquids in surface ponds (Olmstead et al. 2013; Mason, Muehlenbachs, and Olmstead 2015). The 2005 Energy Policy Act exempted fracking from a portion of the Safe Drinking Water Act that regulates underground injection of contaminants, but fracking remains subject to the Clean Water Act.

A short list of additional challenges involving the Clean Water Act includes "combined sewer systems" that dump raw sewage in rivers during heavy storms (primarily in small cities in the Northeast and industrial Midwest); power plants forced to shut off on hot days by their National Pollution Discharge Elimination System permits; the relatively few pollutants that are the focus of the Clean Water Act, whereas US industry manufactures, processes, or imports 33,000 chemical substances (Environmental Protection Agency 2019); air pollution abatement technologies that convert air pollution to surface water pollution; the "total maximum daily load requirements," a regulatory tool with 75,000 local pollution budgets promulgated since 1995 (Environmental Protection Agency 2018a); and the limited prevalence of cap-and-trade markets for water quality (as discussed in this journal in Fisher-Vanden and Olmstead 2013).

Safe Drinking Water Act

Broadly, the Safe Drinking Water Act seeks to protect health by limiting drinking water contamination. The law was popular at its passage—it passed with a voice vote in the Senate and 296–84 in the House (*CQ Almanac* 1974).

The Safe Drinking Water Act includes three main policy instruments. First, it provides a process for setting and enforcing drinking water standards. The Environmental Protection Agency sets an enforceable "maximum contaminant level" for 94 contaminants, including microorganisms such as *E. coli*, radionuclides such as uranium, organic chemicals such as glyphosate (a weed-killer), inorganic chemicals such as cyanide, and disinfectants such as chlorine and their by-products (Environmental Protection Agency 2015, 2018b). States can regulate additional contaminants beyond the 94 on this list. For example, California, but not the EPA, enforces standards on perchlorate, a component of rocket fuel (California Water Boards 2019). The EPA also sets unenforceable "secondary standards" when contaminants create issues involving taste, color, and smell, which have primarily aesthetic importance. While the EPA designs standards, states enforce them, typically using administrative orders, modest civil penalties, or prison, and enforcement is incomplete (Tiemann 2017). A water system can violate these standards by exceeding contaminant limits, by failing to treat water appropriately, or by failing to report tests (Environmental Protection Agency 1999).

Second, the Safe Drinking Water Act authorizes actions to protect groundwater from contamination. This includes regulations of wells drilled for underground fluids (the Underground Injection Control Program); designation of some aquifers as primary drinking water sources, which then prevents any federal funds for purposes that could contaminate these aquifers (the Sole Source Aquifer Program); and protection of areas around groundwater wellheads (the Wellhead Protection Program).

The third main activity involves subsidies for cleaner drinking water. Some subsidies fund drinking water treatment, distribution networks, and related infrastructure, and others provide grants for data management.

The Safe Drinking Water Act regulates roughly 150,000 public and private water systems. About 50,000 of these ("community water systems") provide water to standard homes; the others supply water to sites such as schools, factories, and campgrounds. The largest 400 community water systems cover nearly half the US population, while the smallest 28,000 systems cover only 2 percent of the population (Tiemann 2017). The law does not regulate domestic wells, which serve about 45 million Americans, or bottled water, which the Food and Drug Administration regulates.

Fiscal federalism provides an interesting comparison between the Clean Water Act and the Safe Drinking Water Act. Because rivers flow between states, they provide a classic example of an interjurisdictional externality. Perhaps for this reason, the Clean Water Act provided federal subsidies for wastewater treatment. Drinking water treatment, by contrast, creates less of an externality between cities and jurisdictions, and accordingly, the Safe Drinking Water Act provides less federal funding.

Like the Clean Water Act, the Safe Drinking Water Act also faces some ongoing challenges and issues. Here, we briefly describe four of them.

First, the Safe Drinking Water Act regulates 94 contaminants, but many unregulated chemicals are believed to be toxic and are found in drinking water, including some pesticides and pharmaceuticals. No new contaminants have been regulated since 2006 (Sullivan, Agardy, and Clark 2005; Environmental Protection Agency 2015, 2018b). Concern about toxic chemicals in drinking water is long-standing and has been magnified at times by popular media, going back to Rachel Carson's 1961 book *Silent Spring* and movies such as *A Civil Action* (1998) and *Erin Brockovich* (2000). An example of a contaminant common in drinking water that is not currently regulated would be per- and polyfluoroalkyl substances, which are used to repel water and oil. These chemicals appear in nonstick cookware and pizza boxes, and some evidence links them to cancer and infant health problems (Agency for Toxic Substances and Disease Registry 2018).

Second, lead is a toxic metal that retards brain development. It typically appears in drinking water due to plumbing materials that contain lead, including pipes or soldering. The Safe Drinking Water Act has used increasingly stringent provisions to remove lead from drinking water systems. Recent crises in Flint, Michigan, and elsewhere underscore its continuing challenge (SciLine 2019).

Third, some are concerned that fracking has allowed chemicals to penetrate groundwater, which then feeds into drinking water. Evidence on the prevalence of such pollution is mixed, though households appear willing to pay reasonable sums to avoid such potential contamination (Mason, Muehlenbachs, and Olmstead 2015; Muehlenbachs, Spiller, and Timmins 2015; Wrenn, Klaiber, and Jaenicke 2016).

Fourth, many abatement technologies have increasing returns to scale (Olmstead 2010) and thus are more expensive on a per unit basis for smaller drinking water systems. Water quality regulations are weaker for small or intermittent drinking water systems and nonexistent for rural wells.

How Effective Have These Laws Been?

The extent to which the Clean Water Act and Safe Drinking Water Act affect water pollution depends on how these laws alter enforcement and compliance behavior. For example, to what extent do standards require actual changes? To what extent do regulators test water, and then notify and punish violators? On the compliance side, what is the cost to decrease pollution? These compliance costs evolve on the basis of developments in abatement technologies, which can decrease through learning by doing, economies of scale, or innovation. Additionally, compliance depends on the ability of sources to circumvent these laws—for example, by relocating emissions or reclassifying economic activity.

Existing research does not speak to all of these individual channels of enforcement and compliance, but it does indicate aggregate changes in pollution. Surface water treatment has improved substantially since the early 1970s. In 1940, municipal wastewater treatment plants removed about 20 percent of a common measure of pollution ("biochemical oxygen demand"), and by 1996, they removed nearly 70 percent of it (Environmental Protection Agency 2000b). Industrial treatment has also expanded. In 1954, only 13 percent of water used in large US manufacturing plants had any treatment before discharge; by 1982, 30 percent did (Census Bureau 1971, 1986).[5]

Several studies find evidence of decreased surface water pollution. Some use small sets of monitoring sites (Smith, Alexander, and Wolman 1987; Environmental Protection Agency 2000b), though one finds no change for dissolved oxygen in a large sample

[5] The Survey of Water Use in Manufacturing, which provided these industrial data, was discontinued after the 1980s, though the Census Bureau has recently discussed starting it again.

of lakes (Smith and Wolloh 2012). A national water quality simulation model also suggests substantial decreases in ambient pollution due to observed changes in emissions (Environmental Protection Agency 2000a). More comprehensive evidence comes from 50 million pollution readings from 240,000 monitoring sites (Keiser and Shapiro 2019). That analysis finds that most pollutants have declined substantially, though agricultural pollutants such as nitrates have not. It also finds that the rate of decrease for most pollutants has slowed over time.

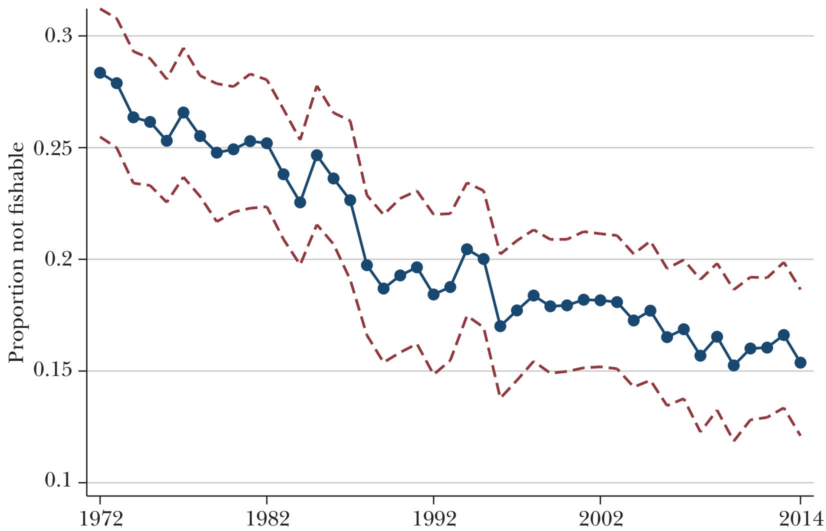
Figure 2 shows an example of this evidence of the substantial decrease in US surface water pollution. This graph summarizes 14.6 million pollution readings covering 265,000 monitoring sites over the period 1972–2014. It shows a common omnibus measure of water quality—whether waters are safe for fishing. This definition of "fishable" is widely used in research; it was developed by William Vaughan for Resources for the Future and reflects published water quality criteria and state water quality standards between 1966 and 1979. When the Clean Water Act passed in 1972, nearly 30 percent of water quality readings were unsafe for fishing. This share has trended steadily downward, and by 2014, only about 15 percent were unsafe.[6] Such decreases could in principle arise from a variety of sources: outsourcing dirty production, productivity growth, environmental lawsuits, or environmental regulation (Shapiro and Walker 2018).

Some studies estimate how much of the change in water pollution can be attributed to the Clean Water Act. Keiser and Shapiro (2019) use a triple-difference research design comparing areas upstream versus areas downstream of wastewater treatment plants and before versus after plants receive grants, across many plants. They find that Clean Water Act grants significantly decrease pollution for 25 miles downstream and for 30 years. Inspections and fines are generally implemented through the National Pollution Discharge Elimination System. Studies exploiting variation in inspections and fines over space and time find that they decrease pollution from wastewater treatment plants and pulp and paper manufacturing (Magat and Viscusi 1990; Laplante and Rilstone 1996; Helland 1998; Earnhart 2004; Glicksman and Earnhart 2007; Gray and Shimshack 2011). For example, Shimshack and Ward (2008) use difference-in-differences regressions for about 250 paper mills in 28 states over 14 years to find that fines on a plant, or on another plant in the same state, are associated with decreases in reported emissions of two common pollutants.

Evidence on trends in drinking water quality and treatment is less clear. Some evidence suggests that drinking water quality has improved, but unfortunately, rather than recording actual pollution concentrations, the best long-term national data record violations of standards, which are more complex to interpret because standards change frequently. The share of community water systems that treat water at all grew substantially between the 1970s and 1990s (Environmental Protection Agency 1999). In 1969, 40 percent of systems violated standards, while in 2015, only 10 percent

[6] Figure 1 in online Appendix A shows similar patterns for the four physical pollutants underlying this measure of whether waters are fishable. For the period 1962–2001, appendix table III of Keiser and Shapiro (2019) shows similar trends in many sensitivity analyses.

Figure 2
US Surface Water Pollution, 1972–2014



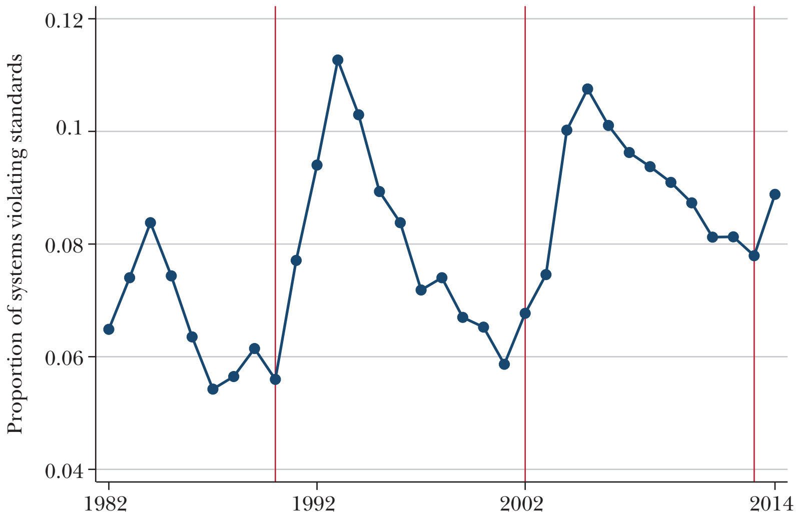
Source: The graph summarizes 14.6 million pollution readings from 265,000 monitoring sites from the Environmental Protection Agency's STORET ("STOrage and RETrieval") Legacy, Modern STORET, and the National Water Information System. See Keiser and Shapiro (2019) for details on the data cleaning procedure.
Note: The graph shows year fixed effects plus a constant from regressions that also control for monitoring site fixed effects, a day-of-year cubic polynomial, and an hour-of-day cubic polynomial. Each observation in the regression is an individual pollution reading at a specific monitoring site; the dependent variable in the regression takes the value one if it violates the fishable standard and zero otherwise. Connected dots show yearly values, dashed lines show 95 percent confidence interval, and 1972 is the reference category. Standard errors are clustered by watershed.

did, even as standards tightened (Public Health Service 1970; Allaire, Wu, and Lall 2018).[7] Figure 3 shows this pattern over the period 1982–2014. This graph shows that violations jump discretely each time the Safe Water Drinking Act incorporates tighter standards, and then the frequency of violations gradually declines as water systems become more likely to comply with the new rule (Allaire, Wu, and Lall 2018).

Some research directly analyzes the effects of the Safe Water Drinking Act and its subsequent amendments. Bennear and Olmstead (2008) exploit variation over time and across drinking water systems to find that the legal requirement for some systems to send annual water quality reports to customers decreased total and health-based water quality violations by more than one-third. Grooms (2016) shows that mean quarterly arsenic concentrations in Californian drinking water follow a linear trend through the early 2000s, then fall by 50 percent in exactly the fourth quarter of 2008, when arsenic standards were tightened. This analysis does not have a control group,

[7] These 1969 and 2015 statistics are not perfectly comparable—each takes a nonrandom sample of drinking water systems, and they focus on different measures of violations.

Figure 3
US Drinking Water Quality Violations, 1982–2014



Source: Data are from Allaire (2018) and cover a balanced panel of 17,900 community water systems.
Note: Vertical lines show years of the most important changes in standards (Total Coliform Rule in 1990, Stage 1 Drinking Water Byproducts Rule in 2002, and Stage 2 Drinking Water Byproducts Rule in 2013). Each point shows the share of community water systems violating health-based standards.

though it does find an abrupt change in a time series. Nigra et al. (2017) show that urinary arsenic concentrations in a national sample of 14,000 Americans had similar trends before the year 2008 for Americans who drank water from public systems versus for Americans who drank well water. After 2008, arsenic concentrations fell for individuals using public water systems but did not change for individuals drinking well water, which did not face new regulations.

How Efficient Has Regulation of Clean Water Been?

The analysis of gains or losses to social welfare from policies to reduce water pollution often involves assessment of three elements: the consumer surplus that people obtain from any decreases in pollution resulting from these policies (including gains due to health, recreation, and other channels), the lost producer surplus from firms due to complying with these regulations, and deadweight loss from taxation to raise revenue for pollution abatement subsidies.

Research has used various methods to investigate these questions. To measure the benefits of cleaner water, some studies use the "travel cost" method, based on changes in where people travel for boating, fishing, or swimming. Others use hedonic methods to analyze changes in home values, look at investments in defensive goods such as bottled water, or study health consequences. Still others use

Table 1
Benefits and Costs of Federal Regulations

	Surface water (1)	*Drinking water* (2)	*Air* (3)	*Greenhouse gases* (4)	*All other* (5)	*All* (6)
A: Total US expenditures (trillions of 2017 dollars)						
1970 to 2014	2.83	1.99	2.11	–	–	–
1973 to 1990	0.94	0.49	0.85	–	–	–
B: Estimated benefits and costs of regulations analyzed in years 1992–2017						
Total benefits / total costs	0.79	4.75	12.36	2.98	1.97	6.31
Mean benefits / mean costs	0.57	8.26	15.18	3.64	21.79	16.17
Share with benefits < costs	0.67	0.20	0.08	0.00	0.19	0.15

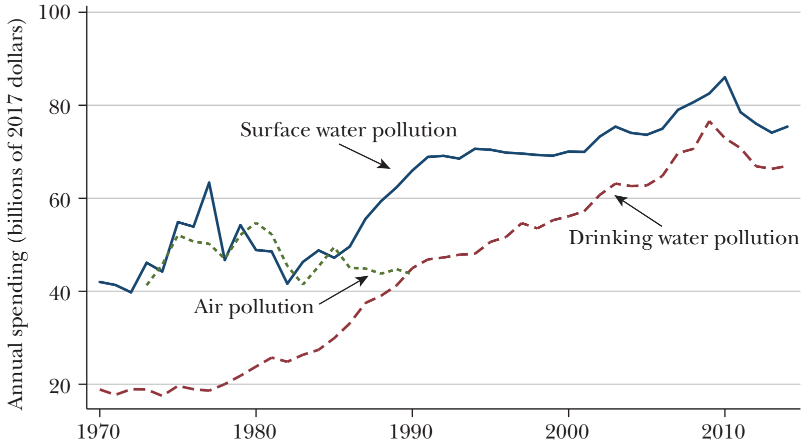
Source: Authors. For years after 2004, data are from table A-1 of the "Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities." For earlier years, data are from various tables of predecessor reports.
Note: Column 5 covers all regulations not in columns 1–4. For studies that estimate a lower bound and upper bound on costs or benefits, this table averages the two. When costs or benefits are estimated for multiple discount rates, this table uses values for a 3 percent discount rate. When studies present multiple estimates for other reasons, this table averages the multiple estimates. The table includes the few studies that report negative costs (that is, cost savings). It also includes studies that contain notes that their benefits or costs are incomplete in specific known ways. The table excludes regulations with unreported benefits or unreported costs, or regulations with benefits and costs not reported in monetary terms or reported in noncomparable monetary terms. The greenhouse gases column includes energy efficiency regulations. For studies listing only a bound (for example, benefits up to $10 million), this table uses the bound. Regulations affecting emissions from all media (as an example, regulating manufacture and disposal of polychlorinated biphenyls) are not listed as air or water policies. Total US expenditures reflect public and private investments (see online Appendix B) and are not readily available for greenhouse gases or all other regulations (columns 4–5).

"stated preference" methods, which include contingent valuation surveys that have been controversial (as discussed in this journal in Diamond and Hausman 1994; Hausman 2012; Kling, Phaneuf, and Zhao 2012). Health-based methods are the most common approach for estimating the value of drinking water quality. To measure the costs of providing clean water, some studies use accounting data from surveys of firm expenditures on pollution abatement, others use engineering estimates of the costs of abatement technology, and still others use reported government accounts.

Panel A of Table 1 shows estimates of the total cost of cleaning up surface water pollution, providing clean drinking water, and abating air pollution.[8] For federal expenditures, we use microdata from a federal accounting database, the Grants Information and Control System, and from annual reports of the Clean Water State Revolving Fund. For state and local expenditures, we use summaries from the Annual Survey of Governments and Annual Census of Governments. For industrial

[8] Online Appendix B describes how we construct these cost estimates in detail, but here we summarize.

Figure 4
Annual Investments to Clean Pollution in Surface Waters, Drinking Water, and Air, 1970–2010



Source: Authors. See sources and details in online Appendix B.
Note: Expenditures include public and private sources, industry, agriculture, transportation (for example, catalytic converters and reformulated gasoline), and all other sources with available data. Air pollution line shows only annual values for 1973 to 1990 because these are the years with the most reliable data; available air pollution expenditure estimates for other individual years require more imputation. All values are deflated to 2017 dollars using the Engineering News Record Construction Price Index.

expenditures, we primarily use data from a survey of manufacturing plants, the Pollution Abatement Costs and Expenditures Survey.

Over the period 1970 to 2014, we calculate total spending of $2.83 trillion to clean up surface water pollution, $1.99 trillion to provide clean drinking water, and $2.11 trillion to clean up air pollution (all converted to 2017 dollars). Total spending to clean up water pollution exceeded total spending to clean up air pollution by 70 to 130 percent.

Figure 4 shows these spending patterns by year. Between 1973 and 1987, annual spending to clean up surface waters was only slightly higher than spending to clean up air pollution, at $40 to $63 billion per year. Spending on drinking water treatment was lower, at $17 to $37 billion per year. Since 1987, spending to treat surface and drinking waters has steadily increased, which might reflect regulation of more toxic pollutants or maintenance of aging infrastructure.

Panel B of Table 1 summarizes benefit-cost analyses of 240 regulations the federal government implemented over the period 1992–2017. For years after 2004, data are from table A-1 of the annual "Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities," which is published by the Office of Information and Regulatory Affairs within the White House Office of Management and Budget. For earlier years, data are from various tables of predecessor reports. For many years, the federal government has completed a prospective evaluation (technically, a "Regulatory Impact Analysis") for all major regulations. This evaluation typically estimates all quantifiable benefits and costs, where possible in monetary terms. The regulation may be implemented regardless of the result, though regulations with unfavorable benefit/cost ratios are more scrutinized. In Keiser, Kling, and Shapiro (2019), we review other studies by academics, which have similar patterns.

For concreteness, we describe one of the studies for surface water summarized in Table 1. In 2004, the Environmental Protection Agency considered requiring the meat and poultry products industry to decrease its water pollution emissions.[9] To evaluate this regulation, the EPA and its contractor Eastern Research Group completed a 1,200-page "Development Document" and a 250-page "Economic and Environmental Analysis." The analysis explains that this regulation would require plants to install abatement technologies such as biological treatment, nitrification, or disinfection. Based on a 350-firm survey and on the 1997 Economic Census, the analysis estimates that this would cost $42 million to $58 million annually. The analysis also estimates that this regulation would decrease emissions of nitrogen from this industry by 60 percent, sediment by 30 percent, and pathogens like *E. coli* by 80 percent. Using a national water quality simulation model (the National Water Pollution Control Assessment Model), the analysis estimates how these decreases in emissions would affect a water quality index from McClelland (1974), then uses stated preference estimates from Carson and Mitchell (1993) to calculate households' associated willingness to pay. The analysis finds that the decreased pollution emissions would lead to benefits of $2.6 million annually, with a range of $0 to $10 million (all figures in 2003 dollars). Given these estimated costs and benefits, this study implies an unfavorable estimated benefit/cost ratio of 0.052 (that is, the estimated benefits are about 5 percent of the estimated costs), with a range of 0.0 to 0.24. The EPA finalized the analysis in February 2004, the final rule was published in the *Federal Register* in September 2004, and the regulation took effect in October 2004.

Table 1 distinguishes five categories of regulations: surface water, drinking water, air pollution, greenhouse gases, and all other (including nonenvironmental). For four of these five categories of regulations, investments pass a benefit-cost test overall. For example, estimated total benefits from air pollution regulations exceed their estimated total costs by a factor of 12. For drinking water studies, total benefits are estimated to exceed total costs by a factor of 5. These are analyses of tightening existing regulation; the net benefits of maintaining existing drinking water treatment may be even greater, because basic drinking water treatment first got rid of typhoid and cholera. Surface water quality (including the meat and poultry regulation described in the previous paragraph) is the only one of these five categories of investment that fails a benefit-cost test—estimated total benefits are only 80 percent of estimated total costs. The next row in Table 1 describes the mean regulation—again all categories have a favorable benefit/cost ratio except surface waters, where

[9] Technically, this was a revision to the industry's Clean Water Act effluent guidelines. This rule finalized the first standards for poultry slaughterers or processors and revised standards for other meat product plants. See Environmental Protection Agency (2014).

the mean regulation has benefits that are 57 percent of its costs. The last row of Table 1 describes the share of regulations that are estimated to have benefits smaller than their costs. For surface water regulations, 67 percent of regulations fail a benefit-cost test; for drinking water regulations, only 20 percent do; and for air pollution regulations, only 8 percent do. Other studies using other samples of regulations reach a similar conclusion that many regulations to reduce surface water pollution fail a benefit-cost test, while most other regulations to reduce pollution pass such a test (Hahn 2000; Keiser, Kling, and Shapiro 2019).

Have investments to clean up US surface waters actually led to negative net benefits, or is existing research underestimating their benefits? Benefit estimates from existing studies may be biased downward for several reasons; investigation of these channels would be valuable for future research (Keiser, Kling, and Shapiro 2019; Keiser and Shapiro 2019). Many studies focus on recreation, amenity, or other types of "use" values that people derive from visiting surface waters. Other "nonuse" or "existence" values for clean water may also be important, though they are difficult to measure well. For example, some people may be willing to pay to decrease pollution in iconic waters such as the Great Lakes, Mississippi River, or San Francisco Bay, even if they never visit these water bodies. One assessment of the Clean Water Act did estimate that nonuse values are only one-sixth as large as use values (Environmental Protection Agency 2000a), but the standard difficulties in measuring nonuse and existence values apply equally well to this analysis.

Other potential benefits are also hard to measure and potentially understated in existing analyses. Many studies ignore health benefits, by assuming that drinking water treatment plants purify any pollution in rivers and lakes before that water reaches households for drinking. For example, in prevailing analyses, health accounts for little to none of the benefits of the Clean Water Act, but for most of the benefits of the Clean Air Act (Keiser, Kling, and Shapiro 2019). Many studies also use restrictive models of pollution transport, even though advances in hydrological routing models could allow more sophisticated analyses of pollution flows. Existing estimates abstract from changes in wages, which are one form in which improvements in market-level amenities such as water quality can be capitalized (Roback 1982). Existing estimates may also overlook changes in the equilibrium relationship of home prices to water pollution, which is another general equilibrium channel (Banzhaf 2018). More broadly, general equilibrium analyses of water pollution policy are limited. Existing estimates also abstract from benefits of reducing toxic and other nonconventional pollutants. Additionally, prevailing estimates generally assume that people have complete information about water pollution. While some newspapers print daily air pollution levels, anything close to this level of information is hard to obtain for water pollution. Furthermore, existing estimates abstract from ecological consequences such as loss of biodiversity and may miss benefits that accrue through groundwater and oceans.

Of course, existing studies may also inaccurately measure costs; the sign of this bias is ambiguous. Abatement costs represent market prices rather than surplus, abstract from market power and any associated loss to customers, ignore potentially valuable by-products from abatement, can be difficult to distinguish from production or safety costs, can lead to learning by doing or innovation that decreases future abatement costs, and can increase the cost of consumer goods and thereby exacerbate distortions due to labor and capital taxes (Cremeans and Segal 1975; Bovenberg and Goulder 1996; Keiser, Kling, and Shapiro 2019).

One could diagnose inaccuracies of estimated benefits and costs for many types of regulation. Are net benefits more severely underestimated for surface water quality than for other goods? Our subjective perception is that cost estimates for water and other types of regulations have similar quality. But for benefits, the channels where environmental goods typically generate especially large benefits are either assumed in the case of water to be nonexistent (health) or hard to measure (nonuse or existence values) (Olmstead 2010). Most existing benefits of surface water quality are believed to come from recreation, but available data on recreation are often geographically limited (for example, one county, state, or lake) and often come from a single cross section. Hence, our subjective perception is that underestimation of benefits is more likely a concern for surface water quality regulation than for other regulations.

Even if current estimates understate the true benefits of investments in surface water quality, several reasons suggest why current and past regulation of surface water quality could produce smaller net benefits than other types of environmental investments (Keiser and Shapiro 2019). Surface water quality policy does not typically use market-based instruments such as cap-and-trade markets, pollution taxes, or hybrids of these two (such as a cap-and-trade market with a price floor). Such policies are generally more cost effective and tend to minimize the cost of pollution abatement. Fisher-Vanden and Olmstead (2013) identified 21 active and pilot programs with trading markets for water pollution permits: two recently created examples are the Chesapeake Bay Watershed Nutrient Credit Exchange and the Minnesota River Basin Trading market. Of course, one reason for the rarity of this approach to water pollution is the concern that it could create local areas of high pollution ("hot spots"). Another reason is that some watersheds have few polluters, and thin markets could lead to higher transaction costs.

Another inefficiency is that current policy ignores much of agriculture, which can make aggregate abatement more costly because current water pollution policy does not equate marginal abatement costs across all sources. Additionally, subsidizing abatement capital, which is primarily how the federal government addresses municipal wastewater treatment, can encourage too much investment in capital rather than in other factors of production such as labor.

Apart from specific policy choices, surface waters may be more substitutable than other environmental goods—changing the river where a person goes fishing or boating may be less costly than changing the air a person breathes (where the person lives or works) or the water a person drinks. Firms, which account for most air pollution abatement, may also find more cost-effective ways to abate water pollution than governments, which account for a large share of water pollution abatement.

Failing a cost-benefit test does not imply the United States should not invest in surface water quality. Apart from the fact that these analyses may underestimate true benefits, they also reflect the policy instruments and investments actually made. Using more cost-effective instruments, targeting investments to areas with greatest net benefits, and other reforms can achieve greater benefits for the same cost. Policymakers may also value other objectives, such as equity.

What is known about the efficiency of water pollution regulation elsewhere? Analysis of the main water quality policy of the European Union, the Water Framework Directive, is too preliminary to be meaningful. The main benefit-cost analysis the European Union's main commissioned report summarizes is for a single watershed in Bulgaria (Russi and Farmer 2018, 53). Some evidence finds that India's National River Conservation Plan has not significantly decreased water pollution (Greenstone and Hanna 2014). Exploiting local discontinuities in regulation, He, Wang, and Zhang (2018) find that reducing China's emissions of chemical oxygen demand, an omnibus measure of industrial pollution, by 10 percent would cost US$160 billion. They do not compare these costs to the associated benefits, though river pollution in China does appear to increase cancer mortality (Ebenstein 2012).

Why a Dearth of Economic Research on Water Pollution?

Given the importance of water quality and the strikingly low estimated benefit/cost ratios, surprisingly little economic research analyzes it. Table 2 describes several measures of research. Publications are perhaps the most relevant measure. Two to three times more JSTOR economics articles focus on the Clean Air Act than on the Clean Water Act or Safe Drinking Water Act. In the top five economics journals, 45 articles discuss the Clean Air Act but only two discuss the Clean Water Act or the Safe Drinking Water Act. Even in environmental and energy economics journals, more than twice as many papers discuss the Clean Air Act than the Clean Water Act or Safe Drinking Water Act. At National Bureau of Economic Research Summer Institute sessions on energy and environmental economics over the years 2009–2018, 21 papers discussed the Clean Air Act and only three discussed the Clean Water Act or Safe Drinking Water Act. We also reviewed eight leading graduate and undergraduate environmental economics textbooks. The mean book spent three times more pages discussing the Clean Air Act than the Clean Water Act. We also reviewed two undergraduate textbooks in public finance; they spent three to six pages discussing the Clean Air Act but did not discuss the Clean Water Act.[10]

Discussing why relatively little economics research has focused on water pollution and its regulation may help explain these surprising patterns and also provide a road map for scholars seeking to start working in this area. One challenge is the

[10] Table 1 in online Appendix A shows that relatively more papers mention water pollution than water pollution regulation. The table measures are less informative, however, since many of these papers focus on unrelated topics (for example, crime) but mention the phrase "water pollution" once.

Table 2
Prevalence of Economic Research on Air versus Water Pollution

	Regulation			*Ratio: air vs. water*	
	Clean Air Act (1)	*Clean Water Act (2)*	*Safe Drinking Water Act (3)*	*Air/ surface (4)*	*Air/ drinking (5)*
Economics journal articles					
All	902	400	87	2.3	10.4
Year 2000+	455	192	38	2.4	12.0
Top five journals	45	1	1	45.0	45.0
Environmental/energy economics	176	65	16	2.7	11.0
Agricultural economics	53	116	19	0.5	2.8
Noneconomics journal articles					
Environment	741	1,106	1,510	0.7	0.5
Health	647	261	581	2.5	1.1
Presentations					
NBER Summer Institute	21	1	2	21.0	7.0
ASSA meetings (AERE sessions)	41	14	3	2.9	2.4
Environmental economics textbooks, no. pages					
Mean	14	4	2	3.5	2.3
Median	11	3	0	3.7	3.7
Public finance textbooks, mean no. pages	4.5	0	0	–	–

Source: All journal articles are from JSTOR. Environmental textbooks include Chapman (2000), Goodstein (2001), Kolstad (2010), Berck and Helfand (2011), Callan and Thomas (2013), Anderson and Libecap (2014), Freeman, Herriges, and Kling (2014), Phaneuf and Requate (2017), and Tietenberg and Lewis (2018). Public finance textbooks include Rosen (2002) and Gruber (2010). The National Bureau of Economic Research (NBER) data cover 2009–2018 environmental/energy economics sessions, while the Allied Social Sciences Association (ASSA) data cover 2011–2019. The ASSA papers include all those in sessions contributed by the Association of Environmental and Resource Economists (AERE). See online Appendix C for additional details.

limited availability of data on surface or drinking water pollution. The Environmental Protection Agency does not operate a comprehensive national monitoring network for water pollution. Many air pollution monitors report values hourly, while the average water pollution monitoring site in one large dataset reports every four months (Keiser and Shapiro 2019). Because many organizations collect water pollution data, using a range of methods and devices, it can be complex to determine which water quality data are accurate, representative, and comparable. Keiser and Shapiro (2019, appendix B.3) describe several methods to address these issues.

One improvement in access to surface water quality data is the Water Quality Portal (http://www.waterqualitydata.us) managed by the Environmental Protection Agency. Fully introduced in June 2018, it streamlines access to a broad range of water quality data. The portal covers about 300 million water quality records, 2.4 million monitoring sites, and 450 monitoring organizations (Read et al. 2017). However, it excludes the largest and oldest federal data repository, the EPA's STORET ("STOrage and RETrieval") Legacy system, which includes 200 million water samples from 700,000 monitoring sites over roughly the years 1900–1998. STORET

Legacy is more difficult to parse, though the EPA plans to incorporate it eventually into the Water Quality Portal. Remote sensing (satellite) measures of water color and clarity are also becoming more common (Lee, Orne, and Schaeffer 2014), as are automatic water quality monitors that can frequently detect and automatically report ambient levels (Anvari et al. 2009). While remote sensing is becoming influential in air pollution research, its use in water pollution research in economics is nascent. For groundwater, one smaller repository, the National Ground-Water Monitoring Network, measures water quality in about 2,000 wells.

For data on drinking water quality, the most comprehensive source is the Tap Water Database, compiled by a nonprofit, the Environmental Working Group. Since 2010, this database has collected data from states. The Environmental Protection Agency also maintains several other records. The Safe Drinking Water Information System begins earlier than the Tap Water Database but reports only violations and not pollution concentrations. The Annual Water Quality Reports is a database of annual reports that water utilities send consumers. Finally, the National Occurrence Database maintains some records of regulated and unregulated water contaminants.

A third challenge for water pollution research involves assessing where and when steps to reduce water pollution have taken place. Some recent progress in data availability may help. The Clean Watershed Needs Survey provides a panel census of the roughly 15,000 wastewater treatment plants that receive household and some business waste in most US cities. The Grants Information and Control System provides data on over 35,000 grants the federal government gave cities through the Clean Water Act to improve wastewater treatment. The Environmental Protection Agency keeps records of inspections and enforcement actions against violators of the Clean Water Act—these data were formerly known as the Permit Compliance System, and a newer, improved version is the Integrated Compliance Information System. The Pollution Abatement Costs and Expenditures survey for many years collected information on firms' capital and operating costs to address pollution emissions. Many of these datasets have existed for decades, though they have gradually become more accessible.

A fourth challenge involves causal inference. Because water quality regulation is somewhat uniform across space, it has been difficult for economists to identify effects of regulation by comparing regulated against unregulated areas. This concern is arguably less pronounced for other environmental goods.

A fifth challenge involves spatial computation. For studying air pollution and climate change, geographic aggregates such as counties or states provide a reasonable unit of analysis. For water pollution, looking at spatial patterns determined by geography—such as upstream and downstream on an individual river segment—can be informative. A few advances have made this form of analysis more feasible. The National Hydrography Dataset provides a georeferenced atlas of every US water feature. Software and computing advances such as ArcGIS, QGIS, C++, and the National Hydrography Dataset have streamflow algorithms, and several papers now exploit the direction of streamflow (Ebenstein 2012; Olmstead et al. 2013;

Cicala 2017; Lipscomb and Mobarak 2017; Garg et al. 2018; Keiser and Shapiro 2019). Also, since 2000, the Watershed Boundary Database has a more spatially detailed watershed called a Hydrologic Unit Code. The most detailed twelve-digit Hydrologic Unit Codes distinguish 100,000 separate local water areas (US Department of Agriculture 2018).

A sixth challenge is the choice of which water pollutants should be the main focus. The surface water pollution repositories discussed above describe over 16,000 different measures of pollution, and it is unclear how to choose a few measures that matter most. Some studies focus on one or a few omnibus measures of water pollution, though the chosen measure varies by study. For example, Sigman (2002) and Lipscomb and Mobarak (2017) use biochemical oxygen demand; Duflo et al. (2013) use biochemical oxygen demand, chemical oxygen demand, and a few others; and Keiser and Shapiro (2019) focus on whether waters are safe for fishing and on "dissolved oxygen," which measures the capacity of water to support aquatic life.

Conclusion

In 1970, the United States created the Environmental Protection Agency, then passed two sweeping laws designed to improve water quality—the Clean Water Act and the Safe Drinking Water Act. The resulting investments in cleaner water have not been cheap, costing on average about 0.8 percent of US GDP per year. A half century later, many measures of drinking and surface water quality have improved, in part because of these laws. Industrial, sewage, and drinking water pollution have all decreased, though agricultural water pollution remains prevalent.

The investments in drinking water appear to create substantial health benefits that exceed their estimated costs. Perhaps surprisingly, however, existing evidence suggests that the estimated costs of most investments in cleaning up rivers, lakes, and oceans exceed their measured benefits. Many of these estimates note that they have difficulty quantifying several important channels of benefits and may be understating true benefits. Unfortunately, economic research on water pollution and its regulation has been limited. An important task for research is to assess which investments in surface water pollution create net benefits, along with ways to make these investments more effective.

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