Burning Waters to Crystal Springs?

U.S. Water Pollution Regulation over the Last Half Century[*]

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ABSTRACT

In the half century since the founding of the U.S. Environmental Protection Agency, public and private U.S. sources have spent nearly $5 trillion ($2017) to provide cleaner rivers, lakes, and drinking water, or annual spending of 0.8 percent of U.S. GDP in most years. Yet over half of rivers and substantial shares of drinking water systems violate standards, and polls for decades have listed water pollution as Americans' number one environmental concern. We assess the history, effectiveness, and efficiency of the Clean Water Act and Safe Drinking Water Act, and obtain four main conclusions. First, water pollution has fallen since these laws, in part due to their interventions. Second, investments made under these laws could be more cost-effective. Third, most recent studies estimate benefits of cleaning up pollution in rivers and lakes which are much less than their costs. Either these analyses systematically understate the value of these investments or these investments are inefficient. Analysis finds more positive net benefits of drinking water quality investments. Fourth, economic research and teaching on water pollution is relatively uncommon, as measured by samples of publications, conference presentations, or textbooks.

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In 1969, the Cuyahoga River in Cleveland, Ohio, lit on fire. A *Time* magazine (1969) article about it attracted enormous attention:

> 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."

Writers attribute many foundational U.S. environmental laws in part to outrage at this fire (Adler 2002; Dingell 2010). The Cuyahoga has not burned since 1969 and today houses forty species of fish (NPS 2018).[1]

Water pollution problems are not merely history. Today, over half of rivers and lakes violate standards, and 4 to 28 percent of Americans in a typical year receive drinking water from systems that violate health-based standards (Allaire et al. 2018; USEPA 2018a). Flint, Michigan, and Pittsburgh, Pennsylvania, recently exposed over 100,000 residents to dangerously high levels of lead in drinking water, and contaminated drinking water leads an estimated 16 million Americans to suffer from gastrointestinal illness each year (Messner et al. 2006). Some worry whether hydraulic fracturing (fracking) has increased chemicals in water.

Polls also suggest that water pollution has been Americans' top environmental concern for at least thirty years. Figure 1 shows the percent of respondents to an annual U.S. Gallup poll who say they are

[1] Historically, the 1969 Cuyahoga fire was unremarkable—rivers in Baltimore, Detroit, Buffalo, Philadelphia, and elsewhere caught fire throughout the 19th and early 20th centuries, and the Cuyahoga had lit on fire at least thirteen times since 1868. The Cuyahoga fire has survived on through music (Randy Newman's "Burn On" and R.E.M's "Cuyahoga"), food and drink (Great Lakes Brewing sells a Burning River Pale Ale, designed to "ignite the senses (not our local waterways)") and other media. Dr. Seuss' original version of *The Lorax* referred to it indirectly, but Seuss removed the reference in 1986 after Ohio graduate students wrote him with evidence of decreased water pollution. In explanation, Seuss wrote, "I should no longer be saying bad things about a body of water that is now, due to great civic and scientific effort, the happy home of smiling fish" (Dierkes 2018).

concerned a "great deal" about various environmental problems. Sixty percent of Americans today list drinking water pollution and also river and lake pollution as a great concern. In every survey since 1989, the share concerned about these issues has substantially exceeded the share expressing concern about air pollution or climate change, and has also exceeded the share expressing concern about other environmental problems (Gallup 2018). A separate poll found that Americans list contaminated drinking water as the third-most serious health problem facing the U.S. (Firth, Kirzinger, and Brodie 2016). Of course, opinion polls do not measure social welfare, but do highlight important political economy forces and prevailing opinions.

Motivated in part by the Cuyahoga fire, Congress tried to fix these problems, in 1970 by creating the Environmental Protection Agency (EPA), in 1972 by passing the Clean Water Act, and in 1974 by passing the Safe Drinking Water Act. A half century later, these laws still manage U.S. surface and drinking water pollution. What forces led to these laws? How do they regulate pollution? How effective and efficient have they been? Finally, why has recent economic research focused relatively little on water pollution, and what can remedy this lack of research? This paper discusses each of these questions in turn.[2]

These questions matter because clean water is potentially important for health, recreation, ecosystems, and more broadly quality of life. These questions also matter because the U.S. has invested an incredible sum of resources to clean up water pollution. The U.S. has spent approximately $4.8 trillion ($2017) to clean up surface water pollution and provide clean drinking water since 1970, or over $400 for every American, every year (Appendix A). In most years, this spending has accounted for around 0.8 percent of U.S. GDP, making clean water arguably the most expensive environmental investment in U.S. history. To put this amount in context, it is less than the average American spends per year on alcohol

[2] Other economic reviews of water pollution regulation appear in Freeman (2000), Olmstead (2010), Griffiths et al. (2012), and Fisher-Vanden and Olmstead (2013). This paper focuses on the U.S.; discussions of water pollution policy in other countries include Ebenstein (2012), Duflo et al. (2013), Greenstone and Hanna (2014), Kahn, Li, and Zhao (2015), and Lipscomb and Mobarak (2017).

($1,200) or residential electricity ($550), and more than the average American spends per year on bottled water ($60) (Dawson 2016; BLS 2018; EIA 2018).[3]

These questions are also important because they provide an excellent setting to learn about externalities, cost-benefit analysis, local public goods, fiscal federalism, regulatory design, non-market valuation, and other classic economic issues. Water pollution is literally the 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.

This paper has several main conclusions. Many measures of drinking and surface water pollution have fallen since the EPA's founding, and the Clean Water Act and Safe Drinking Water Act have caused at least some of these declines.[4] Yet these 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. Furthermore, most studies estimate benefits of regulating surface water quality which are less than their costs, which is not the case for most other government regulations. These estimates of negative net benefits may reflect under-estimates of the true benefits of surface water quality in existing studies. Finally, relatively little economic research focuses on water pollution and its regulation, especially relative to research on air pollution. We discuss several reasons for this relative lack of research, including challenges identifying the economic outcomes that water pollution may effect; limited water pollution data availability; ambiguous spatial structure of water pollution's effects; limited availability of credible research designs; disagreement on the relevant water pollutants, and the complexity of spatial computation.

Before proceeding, it may be useful to clarify differences between three types of waters. The Clean Water Act regulates surface waters (rivers, lakes, and some ocean areas). The extent to which the Clean

[3] Of the $4.8 trillion, about 60 percent addressed surface water pollution and 40 percent drinking water pollution. Another way to divide the $4.8 trillion is that the federal government spent $600 billion, industry spent $600 billion, and state and local governments spent $3.6 trillion to clean surface and drinking waters.

[4] William Ruckelshaus, first head of the Environmental Protection Agency, summarizes, "Even if all of our waters are not swimmable or fishable, at least they are not flammable" (Mehan 2010).

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.

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

Health provided a historic rationale for water quality policy. Sanskrit texts from 4,000 years ago describe purification methods for drinking water that are still used today. Even 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 20th century, many cities began chlorinating and filtering drinking water, and cholera and typhoid rates plummeted (Cutler and Miller 2005; Alsan and Goldin forthcoming). By the 1950s, these investments had nearly eliminated U.S. cholera and typhoid epidemics, and so weakened the health-based rationale for additional investment.

Before the 1970s, the U.S. largely left water quality up to cities and states, but their policy and enforcement was limited. The federal government created some drinking water standards in the early 20th century, but as of 1969, only 59 percent of drinking water systems met these standards (USPHS 1970). For surface waters, federal laws before the Clean Water Act, had limited power. A 1948 law included regulations that Congress described as "almost unenforceable," President Eisenhower called water pollution a "uniquely local blight," and many cities considered rivers to be a public sewer. Regulators often summarized, "The solution to pollution is dilution" (Milazzo 2006). After one of the Cuyahoga River fires, for example, Cleveland prohibited refineries from discharging oil into the Cuyaoga. Violation of this ordnance was only punished with a $10 fine, which was rarely applied (Adler 2002).

The environmental movement helped change this inattention to water pollution. The first Earth Day in 1970 included 20 million people, and was among the largest demonstrations in U.S. history. Proximate

causes of the environmental movement include expanding industrialization producing new pollutants, photographs of Earth taken from space, a major 1969 oil spill off the coast of Santa Barbara, California, and the 1969 Cuyahoga River fire. Deeper causes may have included broader social activism and rising national incomes, together with the fact that clean water is a normal good. Several studies also strengthened support for the Clean Water Act and Safe Drinking Water Act and helped shape both laws (Zwick and Benstock 1971, Harris 1974).

The Cuyahoga River fire was the most proximate cause of the Clean Water Act. The most immediate cause of the Safe Drinking Water Act was the discovery in 1973 of 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 their drinking water as tasting "oily-petrochemical," and fish from the nearby Mississippi River as unsellable due to chemical tastes (USEPA 1972; Agee 1975).[5]

Several aspects of politics from the 1950s and 1960s affected water pollution policy in the 1972 Clean Water Act and beyond. Discussions of surface water pollution had little reference to health.[6] Additionally, because industry opposed regulation, policymakers focused on subsidies to wastewater treatment plants rather than industrial regulation; today both play important roles. Furthermore, 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 disproportionately targeted small towns (Milazzo 2006).

II. How Do These Laws Regulate Pollution?

[5] These precursors to the Clean Water Act and SDWA follow the common phenomenon that economic regulation often follows a crisis—for example, the Dodd-Frank bill regulating the U.S. financial sector was passed after the 2008 financial crisis and Corporate Average Fuel Economy (CAFE) standards were first passed after the 1973-4 Arab oil embargo,

[6] In one debate on the floor of the U.S. House, the main House supporter of this legislation, Congressman John Blatnik, went into what an aide called a "health tirade." His staff expunged these remarks from the *Congressional Record* and replaced them with the written speech text linking water quality and quantity. His staff believed that the lack of waterborne communicable disease epidemics after World War II made health the weakest argument for pollution abatement (Milazzo 2006, p. 29). Today, the Clean Water Act is perhaps the only major environmental regulation of the 1970s and 1980s which does not have health as a main goal (Cropper and Oates 1992).

Clean Water Act

The Clean Water Act's general goals 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.[7] The Clean Water Act was incredibly popular at its inception. President Nixon vetoed the Clean Water Act, due to costs that he called "unconscionable" and "budget-wrecking," but bipartisan majorities in the Senate (52-12, with 36 Senators not voting), and the House (247-23, with one "present" and 160 abstentions) voted to override the veto (CQ Almanac 1972).

The Clean Water Act's first main policy involved grants to cities to improve wastewater treatment plants. In most cities, underground pipes transmit polluted water from homes and businesses to a wastewater treatment plant which abates pollution before discharging treated water to a river, lake, or ocean. The U.S. has around 15,000 such plants.

Congress allocated grant funding across states based on formulas considering state population, forecast population, and wastewater treatment needs (CBO 1985). Within a state, grants were allocated based on a "priority list" that states submitted annually to the EPA. These grants began in 1957 under predecessor laws to the Clean Water Act, though 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 ($2017)—about $230 billion in federal grant funds, $110 billion in municipal matching funds, and $530 billion in operation and maintenance costs (Appendix A).[8] In 1987, the grants program transitioned to a subsidized loan program, the Clean Water State Revolving Fund.

The Clean Water Act's second main policy involved permits distributed to sources discharging pollution from a fixed source (e.g., a pipe) into navigable surface waters—the National Pollution Discharge Elimination System (NPDES). Each permit describes the levels of pollution the plant may discharge. These

[7] 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.

[8] These figures represent U.S. EPA grants distributed from 1960 to 2005 per Keiser and Shapiro (2019). Corresponding operations and maintenance costs are calculated as in Keiser and Shapiro (2019) and represent costs attributable to these capital investments through 2014.

permits focus on five conventional pollutants (e.g., bacteria like fecal coliform) and 126 "priority" toxic pollutants, though may cover other water quality measures (USEPA 2010). Regulators may issue different types of NPDES permits, including a stormwater permit describing runoff permitted during rains; a general permit covering a group of similar sources in the same area; or an individual permit.

Table 1 shows the breakdown of this NPDES regulation across industries. Around 130,000 of these permits have been issued (EPA 2018c). Among all of these permits, roughly 10 percent each cover agriculture & fishing, mining, and construction, 15 percent cover manufacturing, a fourth cover utilities (especially wastewater treatment), and a fifth cover services. Most of these permits cover small pollution sources. Among the most important ("major") permits, two-thirds cover wastewater treatment and associated sewerage. Among the other major permits, over half cover manufacturing (especially paper, chemicals, metals, and oil refining), a fourth cover power plants and associated electric services, and the rest are scattered among other industries.

Challenges Involving the Clean Water Act

We highlight a few other historic and current concerns in Clean Water Act regulation. In part because the Clean Water Act largely ignores agricultural pollution, agriculture contributes to some of the worst surface water quality problems. This includes a massive "Dead Zone" in the Gulf of Mexico where oxygen levels fall too low to support most aquatic life and significant degradation of the Chesapeake Bay. For political economy and technical reasons, regulators have found it difficult to regulate pollution from agriculture.[9]

Another Clean Water Act challenge involves recent litigation. In the last 15 years, judicial rulings have restricted, reinstated, and then again restricted Clean Water Act protections for roughly half of U.S. waters, primarily wetlands, headwaters, and intermittent streams.[10] The Clean Water Act only protects

[9] One exemption which the Clean Water Act has regulated is concentrated animal feeding operations (CAFOs), which the Clean Water Act regulates with individual or area NPDES permits and treats similarly to other direct pollution dischargers.

[10] The Supreme Court *Rapanos* and *SWANCC* decisions restricted Clean Water Act protection for these waters; the Obama administration's 2015 Waters of the United States Rule (also called the Clean Water Rule) sought to

"Waters of the United States"; these debates are litigating which waters that clause protects. The net benefits of these regulations have also become controversial (Boyle, Kotchen, and Smith 2017).

An additional Clean Water Act issue involves hydraulic fracturing (fracking). 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. Fracking has increased U.S. gas and oil production, but has inspired concerns of contaminating ground and surface waters due to chemicals leaking from underground wells, improper cement casing around the well, or improper storage of fracking liquids in surface ponds (USEPA 2016). The 2005 Energy Policy Act exempted fracking from portions of the Safe Drinking Water Act and Clean Water Act.[11]

A further current challenge to the Clean Water Act is the rapid expansion of pollutants. U.S. industry produces 85,000 chemicals; industrial and wastewater treatment plants only seek to treat a far smaller number. For example, a General Accounting Office (1994) analysis of 236 industrial plants found that their NPDES water pollution permits ignored over three-fourths of the types of toxic pollutants they emitted, that many of these ignored toxic pollutants were known to cause health risks, and that toxic pollutants not on the Clean Water Act's "priority" list account for 98 percent of discharges by mass in a national emissions database, the Toxic Release Inventory.

We mention a few additional challenges involving the Clean Water Act briefly. Some cities have a single set of underground pipes designed to transmit both wastewater and rain from storms; severe rainfall overwhelms wastewater treatment plants in such cities and leads these "combined sewer systems" to discharge raw untreated sewage and wastes into surface waters. Power plants create enormous water demand for cooling, in total accounting for 40 percent of total U.S. water withdrawals (Hutson et al. 2003).

reinstate it; many states sued to vacate the rule; and in 2017 President Trump issued an executive order to rescind or revise the rule.

[11] Fracking is exempt from the portion of the SDWA which regulates underground injection of contaminants, though the EPA announced in 2014 that wells involve underground injection of diesel fuels for fracking are still subject to the SDWA (Tiemann and Vann 2015). In the Clean Water Act, fracking wells are subject to standard NPDES permits, but are not required to hold storm water runoff NPDES permits describing the fate of precipitation runoff that may contain petroleum (USEPA 2019).

Thermal pollution from power plants can be constrained by NPDES permits specifying high river temperatures on precisely the summer afternoons when electricity demands are high.[12] Some air pollution abatement technologies convert pollution from air to water, and increasingly stringent air pollution regulation could increase surface water pollution (Greenstone 2003; Duhigg 2009; Gibson forthcoming). The EPA has begun using a new tool, Total Maximum Daily Load (TMDL) requirements. A TMDL specifies the maximum level of discharge for a specific pollutant which a water body can receive in order to meet desired uses, then describes changes in emissions needed from each source to achieve the desired use. The EPA has issued 75,000 TMDLs since 1995 (USEPA 2018a). Cap-and-trade markets for surface water pollution have been uncommon, small, and plagued by transaction costs; expanding the scope of such trading could substantially increase the cost effectiveness of water quality policy (Fisher-Vanden and Olmstead 2013). Last, the Clean Water Act set national water quality standards for different desired uses; regulators have debated the appropriate levels of these standards and the extent to which they should vary across space and desired use.

Safe Drinking Water Act

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

The SDWA includes three main policy instruments. The first involves setting and enforcing drinking water standards. The EPA sets an enforceable "maximum contaminant level" for 94 contaminants, including microorganisms like *E. Coli*; radionuclides like uranium; organic chemicals like glyphosate (Roundup); inorganic chemicals like cyanide; and disinfectants and their byproducts like chlorine (USEPA 2015, 2018b). The EPA also sets non-enforceable "secondary standards" for contaminants like taste, color, and smell, which have primarily aesthetic importance. A water system can violate these standards by

[12] Power plants typically extract water, use it for cooling, then return it to rivers warmer, while other sectors that extract water (e.g., agriculture) typically consume most of the water they withdraw.

exceeding contaminant limits, failing to treat water appropriately, or failing to report tests (USEPA 1999). Water systems can also avoid violations strategically, for example by oversampling when initial readings exceed limits (Bennear, Jessoe, and Olmstead 2009).

While the EPA designs standards, states enforce them, typically using administrative orders, modest civil penalties, or prison (Tiemann 2007). Enforcement is incomplete. In fiscal year 1987, for example, 3 percent of violations led to any state enforcement, and only five hundredths of a percent of violations led to EPA enforcement actions (Munson 1989).

The SDWA's second main policy involves protecting 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 SDWA's third main activity involves subsidies for drinking water. One set of subsidies funds drinking water treatment, distribution networks, and related infrastructure. Another provides grants for managing databases, conducting surveys, and other activities for managing water-related information. A third provides grants and subsidized loans to rural communities for drinking water and wastewater treatment.

The SDWA regulates roughly 150,000 public and private water systems. About 50,000 of these ("community water systems") provide water to year-round households; the others supply other sites like schools, factories, campgrounds, and such. The largest 400 community water systems cover nearly half the U.S. population, while the smallest 28,000 systems cover only 2 percent of the population (Tiemann 2017). The SDWA does not regulate domestic wells, which serve about 45 million Americans, or bottled water, which is regulated by the Food and Drug Administration. About 70 percent of community water system customers receive water from systems with surface water sources, while the others have groundwater sources (USEPA 2009).

Challenges involving the Safe Drinking Water Act

We also discuss a few current concerns involving the SDWA. First is the choice of contaminants. The SDWA regulates 94 of about 85,000 industrial chemicals; many unregulated chemicals are believed to be toxic and are found in drinking water, including some pesticides and pharmaceuticals (Sullivan, Agardy, and Clark 2005). Concern about toxic chemicals in drinking water is longstanding and magnified by popular media, including Rachel Carson's 1961 book *Silent Spring* and the films "Erin Brockovich" and "A Civil Action." For example, one contaminant common in drinking water but not regulated is per- and polyfluoroalkyl substances (PFASs), used to repel water and oil. These chemicals appear in non-stick cookware, pizza boxes, and many other products, and may contribute to cancer and infant health problems; the EPA is deciding whether to regulate them.

Another current SDWA concern involves lead, a toxic metal which retards brain development. Lead typically appears in drinking water due to plumbing materials including pipes or soldering. The SDWA has used increasingly stringent provisions to remove lead from drinking water systems. Recent crises in Flint, Michigan, and elsewhere underscore its continuing challenge.

An additional SDWA concern involves fracking. 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).

A final set of SDWA concerns involves wells and small drinking water systems. In part because many abatement technologies have increasing returns to scale (Olmstead 2010), water quality regulations are weaker for small or intermittent drinking water systems, and nonexistent for rural wells. The smallest drinking water systems are often most likely to violate standards.

III. How Effective Have These Laws Been?

Relevant Parameters

The extent to which the Clean Water Act and SDWA affect pollution depends on a few legal and economic parameters. One is de jure and de facto stringency—to what extent do standards require substantial changes for new or entrant plants? Moreover, did regulators test water, notify and punish violators, and change behavior?

Another issue involves compliance. What is the cost for sources to decrease pollution? Compliance costs also depend on invention of new abatement technologies and on the costs of existing 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.

Evidence

Existing research does not always speak to these individual channels, but 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 2000, they removed 70 percent of it (USEPA 2000). Industrial treatment has also expanded—in 1954, only 13 percent of water used in large U.S. manufacturing plants had any treatment before discharge; by 1982, 30 percent did (U.S. Census 1971, 1986).

Several studies find evidence that surface water pollution has declined. Some use small sets of monitoring sites (Smith, Alexander, and Wolman 1987, USEPA 2000), though one finds no change for dissolved oxygen in a large sample 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 (Bingham et al. 2000). 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 like 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 U.S. surface water pollution since the Clean Water Act. This graph uses 14.6 million pollution readings covering 265,000 monitoring sites over the period 1972-2014. This graph shows a common omnibus measure of water quality—whether waters are safe for fishing.

Figure 2 shows that 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. Appendix Figure 1 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.

Some studies directly attribute some of the change in pollution to the Clean Water Act. Keiser and Shapiro (2019) use a triple-difference research design comparing areas upstream versus downstream of wastewater treatment plants and before versus after plants receive grants and across many plants; they find that Clean Water Act grants significantly decrease pollution for 25 miles downstream and for 30 years. Inspections and fines, implemented through NPDES regulation, decrease pollution from wastewater treatment plants, pulp and paper manufacturing, chemical manufacturing (Magat and Viscusi 1990; Laplante and Rilstone 1996; Helland 1998; Earnhart 2004; Shimshack and Ward 2005; Glicksman and Earnhart 2007; Shimshack and Ward 2008; Gray and Shimshack 2011).

Evidence on trends in drinking water quality and treatment is less clear, though suggests improvements. The share of community water systems which treat water at all grew substantially between the 1970s and 1990s (USEPA 1999). In 1969, 40 percent of systems violated standards, while in 2015, only 10 percent did, even as standards tightened (USPHS 1970; Allaire, Wu, and Lall 2018).[13] Figure 3 shows data from a recent study of 18,000 community drinking water systems over the period 1982-2015. This graph shows that violations jump discretely each time the SDWA incorporates tighter standards, and then the frequency of violations gradually declines as water systems become more likely to comply with the new

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

rule (Allaire, Wu, and Lall 2018). Many of the spikes in this graph reflect violations of water quality standards induced a few years earlier (for example, increase in violations around the year 2005 is in large part due to violations of the year 2002 Stage 1 Drinking Water Byproducts rule). Over this period, 10 to 45 million people per year drank water violating health standards.

Limited evidence directly analyzes the effects of the SDWA and its subsequent amendments. Bennear and Olmstead (2008) find that the SDWA requirement to send annual water quality reports to customers decreased total and health-based water quality violations by more than a third. Grooms (2016) shows that mean arsenic concentrations in California follow a slightly decreasing trend through the early 2000s, but abruptly fell 50 percent in 2008 when arsenic standards were tightened. Nigra et al. (2017) find that arsenic concentrations in a sample of Americans decreased for individuals using public water systems but not for individuals drinking well water, in tandem with arsenic regulations in public systems.

IV. How Efficient Are These Laws?

Determining how these policies affected pollution does not indicate how they affect well-being. Analysis of social welfare often involves assessment of the consumer surplus that people obtain from any decreases in pollution resulting from these policies (including due to health, recreation, and other channels); the lost producer surplus from firms due to complying with these regulations; and deadweight loss of taxation associated with government spending.

Research has used a range of methods to investigate these questions. To measure the benefits of cleaner water, some studies look at changes in where people travel for boating, fishing, or swimming (travel cost methods); others analyze changes in home values (hedonic methods); others look at investments in defensive goods like bottled water (averting investments); others look at health consequences; and others use stated preference methods (contingent valuation methods and choice experiments).[14] Stated preference

[14] A very incomplete list of studies and associated discussions includes Freeman (1982), Smith and Desvousges (1986), Bockstael, Hanemann, and Kling (1987); Carson and Mitchell (1993), Lyon and Farrow (1995), Leggett and Bockstael (2000), Murdock (2006), Egan et al. (2009), Moeltner and von Haefen (2011), Currie et al. (2013),

methods are the most common approach for estimating the value of surface water quality, though have been controversial (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. These different approaches have numerous tradeoffs (Freeman, Herriges, and Kling 2014). 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 others use reported government accounts.

Table 2, row 1, shows estimates of the total cost of cleaning up surface water pollution, providing clean drinking water, and abating air pollution over the period 1970-2014 (Appendix A provides details). Over this period, we calculate total spending of $2.8 trillion to clean up surface water pollution, $2.0 trillion to provide clean drinking water, and $2.1 trillion to clean up air pollution ($2017). By each measure, total spending to clean up surface water pollution alone exceeded total spending to clean up air pollution. Total spending to clean up surface plus drinking water pollution exceeded total spending to clean air pollution by 70 to 130 percent. One potential contributor to these patterns may be that most air pollution abatement is undertaken by profit-maximizing private firms, whereas most water pollution abatement is undertaken by governments which may have other types of objectives. Of course, abatement expenditures do not represent the total change in producer surplus—for example, they represent market prices rather than surplus, abstract from market power and any associated loss to customers, and ignore general equilibrium effects (Keiser, Kling, and Shapiro Forthcoming).

Figure 4 shows these total 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 much lower, at $17 to $37 billion per year. Since 1987, spending to treat surface and drinking waters has steadily increased, which could reflect regulation of more toxic pollutants or maintenance of aging infrastructure.

Kuwayama and Olmstead (2015), Muehlenbachs, Spiller, and Timmins (2015), Boyle, Kotchen, and Smith (2017), Keiser and Shapiro (2019), and Keiser (forthcoming).

Table 2, rows 3-5, summarizes benefit-cost analyses of 240 regulations the federal government implemented over the period 1992-2017. This table distinguishes five categories of regulations: surface water; drinking water; air pollution; greenhouse gases; and all other (including non-environmental). This table shows that four of these five categories of investments pass a benefit-cost test. For example, estimated total benefits from air pollution regulations exceed their estimated total costs by a factor of 12. For drinking water, total benefits are estimated to exceed total costs by a factor of 5. Surface water quality is the only one of these five categories of investment which fails a benefit-cost test—estimated total benefits are only 80 percent of estimated total costs. The next row in Table 2 describes the mean regulation—again all categories have a favorable benefit/cost ratio except surface waters, where the mean regulation has benefits that are 57 percent of its costs. The last row of Table 2 describes the share of regulations which 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.

To make this comparison clearer, Figure 5 shows a histogram of these air and water pollution analyses. This Figure makes the conclusion even clearer—most recent federal surface water quality regulations have estimated benefits which are smaller than their estimated costs. By contrast, most air pollution regulations have estimated benefits which far exceed their estimated costs. Other studies using other samples of regulations find similar conclusions (Hahn 2000; Keiser, Kling, and Shapiro 2018).

This stylized fact, that most cost-benefit analyses estimate negative net benefits of surface water quality regulations, leads to a critical question. Do investments to clean up surface waters actually create negative net benefits to the U.S., or is existing research underestimating their benefits? Benefit-cost ratios from existing studies may be systematically biased for several reasons—many studies ignore health benefits, use restrictive models of pollution transport, under-count non-use values (e.g., people may be willing to pay to clean up the Mississippi River even if they never visit it), ignore general equilibrium channels, exclude benefits from toxic and other non-conventional pollutants, assume that people have

complete information about water pollution, exclude benefits from groundwater and ocean waters; and ignore ecological consequences like loss of biodiversity (Keiser, Kling, and Shapiro forthcoming).

Even if current estimates understate the true benefits of investments in surface water quality, several reasons suggest why regulation of surface water quality could produce smaller net benefits than other types of environmental investments (Keiser and Shapiro 2019). Cap-and-trade markets or pollution taxes generally minimize the cost of pollution abatement, but surface water quality regulation rarely uses these. Additionally, surface water quality regulation largely ignores agriculture, which can make aggregate abatement more costly. Furthermore, substituting between rivers for recreation has lower cost than sources of air or drinking water. Finally, surface water quality regulation, unlike most environmental policies, is believed to produce few health benefits.

It is also worth emphasizing that failing a cost-benefit test does not imply the U.S. 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 like cap-and-trade markets or pollution taxes, 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, like equity.[15] Firms, which account for most air pollution abatement, may also find more cost-effective ways to abatement pollution than governments, which account for most water pollution abatement.

V. Why a Dearth of Economic Research?

Given the importance of water quality and its regulation, relatively little economic research analyzes it. Table 3 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 the Clean Water Act. In the top five economics journals, 53 articles discuss the Clean Air Act but only 5 discuss the Clean Water Act or the Safe Drinking Water Act. Even in environmental and energy economics journals,

[15] A large literature on "environmental justice" discusses the extent to which air pollution exposure varies with socioeconomic status; less of this literature

about 50 percent more papers focus on the Clean Air Act than on the Clean Water Act or Safe Drinking Water Act.[16]

Table 3 also investigates these imbalances in two other fields of academia—environmental sciences and health. In environmental sciences, about the same number of papers analyze the Clean Air Act and Clean Water Act. In health, a similar number of papers study the Clean Air Act as study the Clean Water Act or SDWA. These patterns suggest that whatever forces have shifted economics research towards air rather than water pollution, these forces have not produced the same effects outside of economics.

Conference presentations provide another measure of research activity. At NBER Summer Institute meetings on energy and environmental economics (EEE) over the last decade, 24 papers focused on air pollution, 3 covered surface water pollution, and only 2 covered drinking water pollution. We also reviewed eight leading graduate and undergraduate environmental economics textbooks. The mean book spent two and a half times more pages discussing air pollution than discussing water pollution. We also reviewed two undergraduate textbooks in public finance; they spent 3-6 pages discussing air pollution and did not discuss water pollution.

We now turn to discuss several reasons why little economic research has focused on water pollution and its regulation, and mention progress on some. One challenge involves linking water pollution to outcomes. Levels and regulations of many environmental goods – air pollution, weather, climate, toxic sites – affect crop yields, health, land values, crime, firm productivity, firm outsourcing, capital investment, income, and labor earnings in ways that econometrics can detect and analyze. Researchers have less consensus on whether and to what extent such choices and outcomes respond to drinking or surface water pollution, which may discourage research in this area, and may also contribute to the low existing estimates of net benefits highlighted in the previous section. It is unclear if this uncertainty is because water pollution truly has smaller effects on economic choices and outcomes, or because water pollution's effects are more difficult to detect in data. The difficulty in detection could be because the effects are small, or because the

[16] This review does not separately seek to measure research on water quantity, e.g., groundwater depletion, which is its own area of research.

spatial links between water pollution and its benefits are more complex (see below).[17] The polls highlighted in Figure 1 suggest that many Americans believe surface water pollution adversely affect important outcomes; the challenge here is that researchers have not well been able to identify which outcomes are actually affected.

A second challenge to economic research on water pollution is the limited availability of data on surface or drinking water pollution. Many air pollution monitors report values hourly, while the average water pollution monitoring site in one large sample reports only every four months (Keiser and Shapiro 2019). In part this is because surface water pollution monitoring more often requires a person visiting (e.g., in a boat) to take samples and potentially analyze in a lab, and because the EPA does not operate a standard national monitoring network. Because many organizations collect these data, using a range of methods and devices, in varying locations, it can also be complex to determine to what extent existing water quality data are accurate, representative, and comparable across time and space. Appendix B.3 of Keiser and Shapiro (2019) does describe several methods to assess and address these issues.

One development that has improved access to surface water quality data is the Water Quality Portal (www.waterqualitydata.us). Fully introduced in June 2018, it provides streamlined access to three federal data repositories—Modernized STORET, the National Water Information System, and STEWARDS. It covers about 300 million water quality records, 2.4 million monitoring sites, and 450 monitoring organizations (Read et al. 2017). This portal excludes the largest federal data repository, STORET Legacy, 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 EPA plans eventually to incorporate it into the Water Quality Portal. Remote sensing (i.e., satellite) measures of water color and clarity are also becoming available (Lee et al. 2014). For groundwater, one smaller repository, the National Ground-Water Monitoring Network, measures water quality in about 2,000 wells.

[17] Air pollution also moves in complex ways through space. The difference we seek to highlight here is that knowing where someone lives and works provides good information on what air pollution they ingest. By contrast, knowing where someone lives and works provides much less information on the extent to which they interact with nearby surface water pollution.

The most comprehensive source for drinking water quality data is the Tap Water Database, compiled by a nonprofit, the Environmental Working Group. Since 2010, this database has sought to collect data from states. The EPA's main database, the Safe Drinking Water Information System (SWDIS), begins earlier but only reports violations and not pollution concentrations. The EPA also keeps a database of annual reports that water utilities send consumers (Annual Water Quality Reports), and maintains some records of regulated and unregulated contaminants (the National Occurrence Database).

A third challenge to economic research on water pollution involves assessing where and when water pollution and its regulation are relevant. Because economic research on water pollution regulation is not widespread, there is no general consensus on how to measure it. 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 U.S. cities. The Grants Information and Control System (GICS) provides data on over 35,000 grants the federal government gave cities through the Clean Water Act to improve wastewater treatment. The EPA 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 (ICIS) 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 have gradually become more widely accessible.

A fourth challenge involves research designs. Because water quality regulation is relatively uniform across space, it has been difficult for economists to identify effects of regulation by comparing regulated against unregulated areas. This concern is less pronounced for other environmental goods—the Clean Air Act, for example, has nonattainment designations which vary according to ambient air levels across counties and time, and the panel variation in weather used in recent studies of climate change (Dell, Jones, and Olken 2014) is fairly random.

A fifth challenge to economic research on water pollution is the choice of pollutants. The surface water pollution repositories discussed earlier describe over 16,000 different measures of pollution, and it is

unclear which 1-2 measures matter most. Some studies focus on one or a few omnibus measures of water pollution, though the chosen measure varies by study—Sigman (2002) and Lipscomb and Mobarak (2018) focus on biochemical oxygen demand (BOD); Duflo et al. (2013) focus on BOD, chemical oxygen demand, and a few others; some studies use a water quality index (Sigman 2005); and Keiser and Shapiro (2019) focus on whether waters are safe for fishing and on dissolved oxygen, though also discuss results from other physical pollutants. Toxic pollutants may be disproportionately relevant for health and well-being, though are less often measured in these data.

A sixth challenge involves spatial computation. For studying air pollution and climate change, simple geographic aggregates like counties or states provide a reasonable unit of analysis. For water pollution, analyzing patterns at the level of individual river segments and their upstream and downstream relationships can be informative but computationally costly, both in computer and human time. A few advances have made this more feasible. One is the National Hydrography Dataset, which provides a georeferenced atlas of every U.S. water feature. Software and computing advances have also made such calculations more feasible. 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 useful is the development of increasingly detailed measures of water regions, technically called Hydrologic Unit Codes (HUCs). Since 2000, the Watershed Boundary Database has defined more spatially detailed HUCs, which can provide a simpler alternative to upstream and downstream calculations. The most detailed, 12-digit HUCs, distinguish 100,000 separate local water areas (USDA 2018).

VI. Conclusions

Access to clean water has been a central issue in human health for millennia. Historically water pollution spread typhoid, cholera, and other infectious disease, leading to high infant and urban mortality around 1900. Partly in response to the environmental movement, the U.S. in 1970 created the Environmental

Protection Agency, and then passed two sweeping laws designed to improve water quality—the Clean Water Act and the Safe Drinking Water Act.

A half century later, many measures of drinking and surface water quality have improved, in part because of these laws. U.S. rivers used to light on fire regularly, and since the Clean Water Act have done so rarely if ever. Industrial, sewage, and drinking water pollution have all decreased (though agricultural pollution remains prevalent).

These investments have not been cheap. On average they have cost 0.8 percent of U.S. GDP per year, or over $400 for every American, every year. These investments are potentially important, and also popular. In surveys over the past 30 years, for example, Americans every year list drinking and surface water pollution as their top two environmental concerns. Investments in drinking water appear to create substantial health benefits which exceed their estimated costs.

Surprisingly, however, existing evidence suggests that estimated costs of most investments in cleaning up rivers, lakes, and oceans exceed their measured benefits. In part for these reasons, two Supreme Court cases, an Obama Administration Executive Order, and the Trump Administration have all litigated whether to rescind Clean Water Act protections for about half of U.S. surface waters. Is existing analysis systematically undercounting the benefits of these investments? Unfortunately, economic research on water pollution and its regulation has been limited. Better understanding the extent to which these investments in surface water pollution create net benefits to the U.S., and ways to make these investments more effective, is critical.

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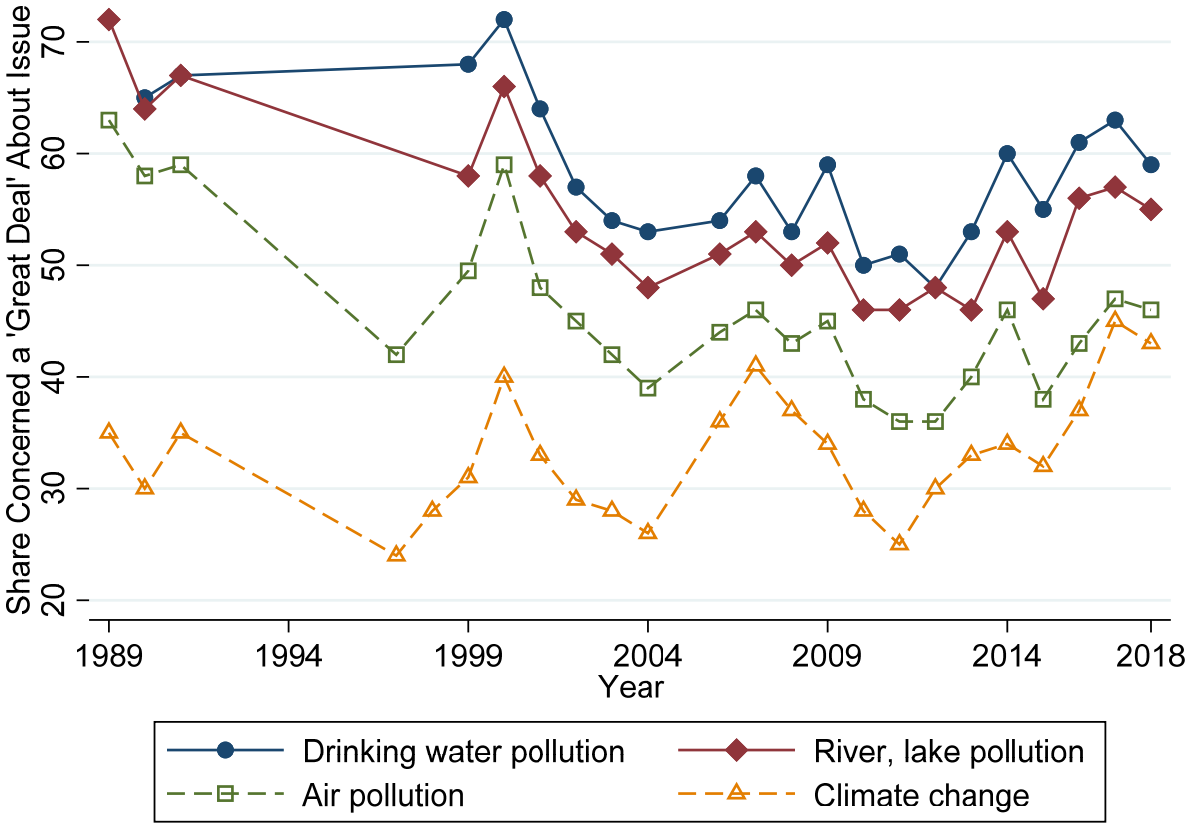
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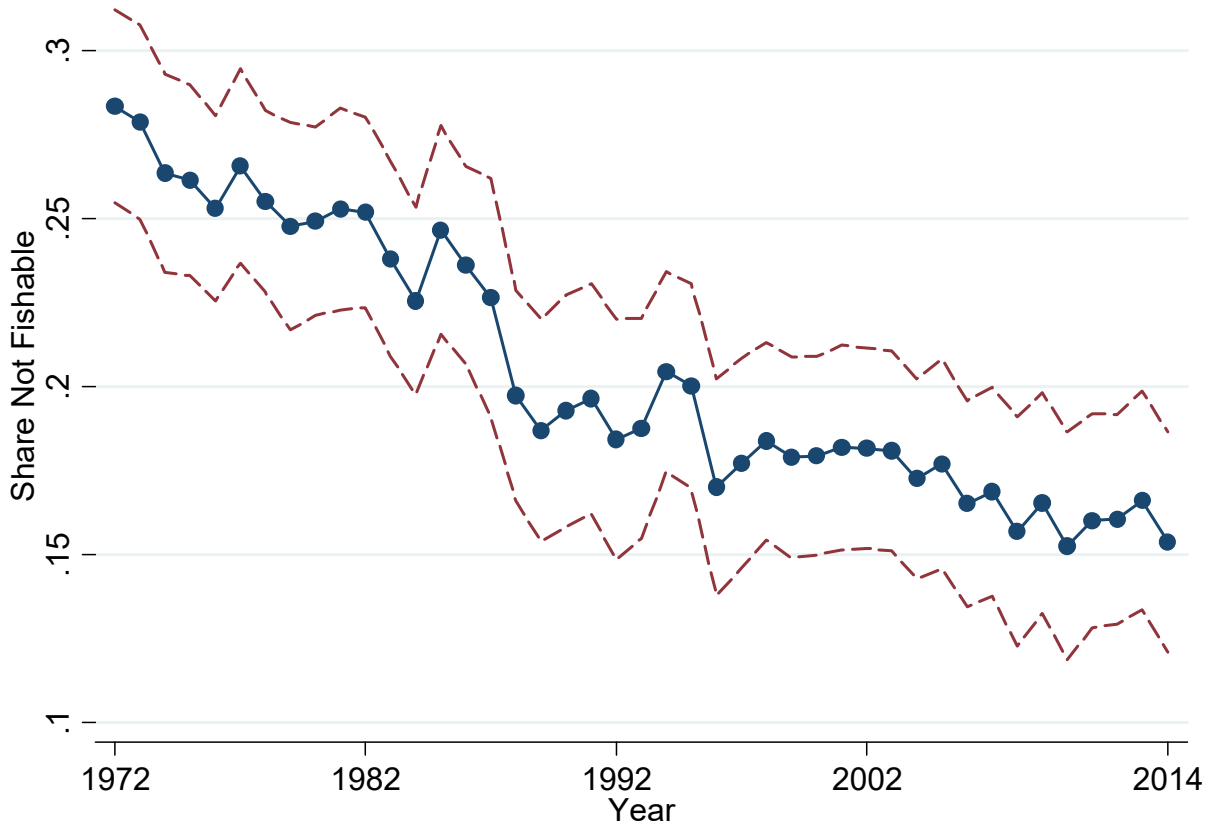
Figure 1

Share of Americans Concerned "A Great Deal" about Various Environmental Issues, 1989-2018



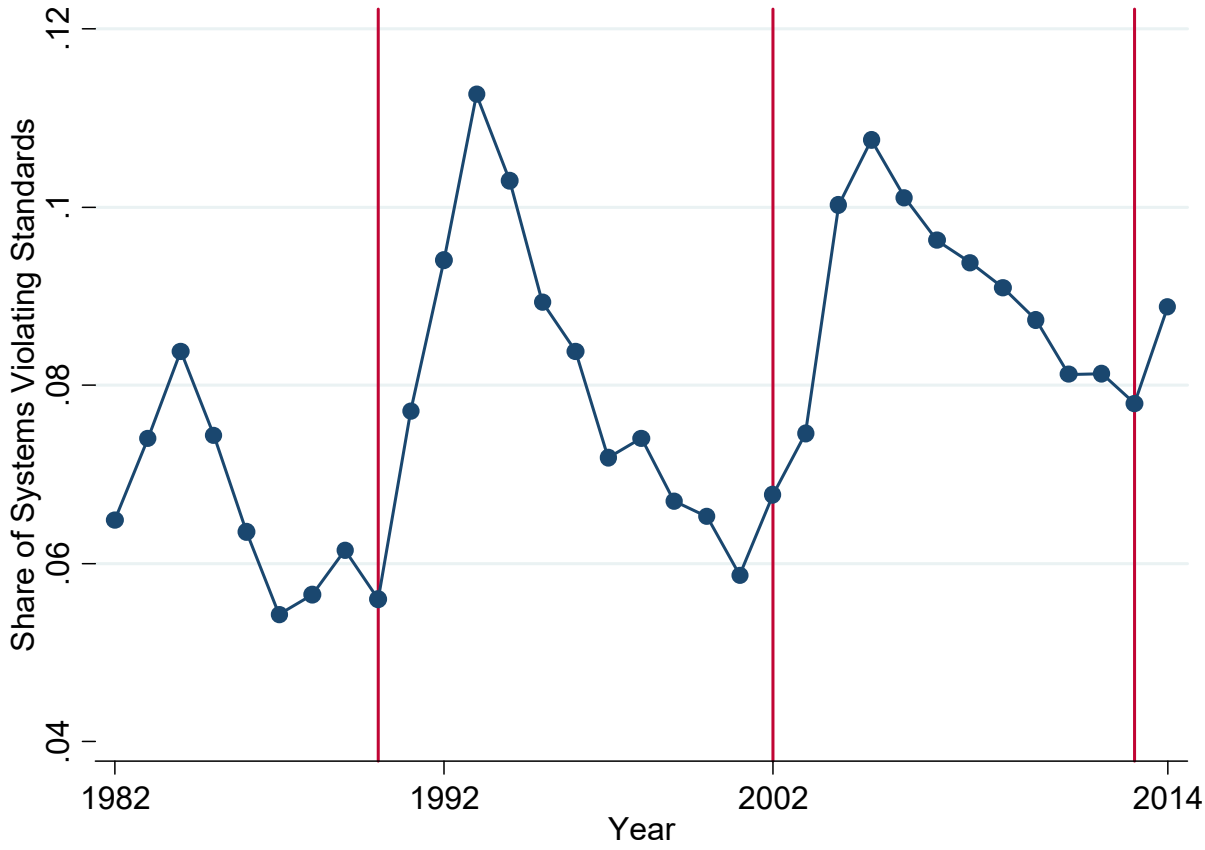
Source: Gallup (2018). Each poll asks, "I'm going to read you a list of environmental problems. As I read each one, please tell me if you personally worry about this problem a great deal, a fair amount, only a little or not at all." The graph shows four issues to avoid too many lines obscuring the main 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 also river and lake pollution equals or exceeds stated concern about each of these other issues in nearly every year of the survey.

Figure 2
U.S. Surface Water Pollution, 1972-2014



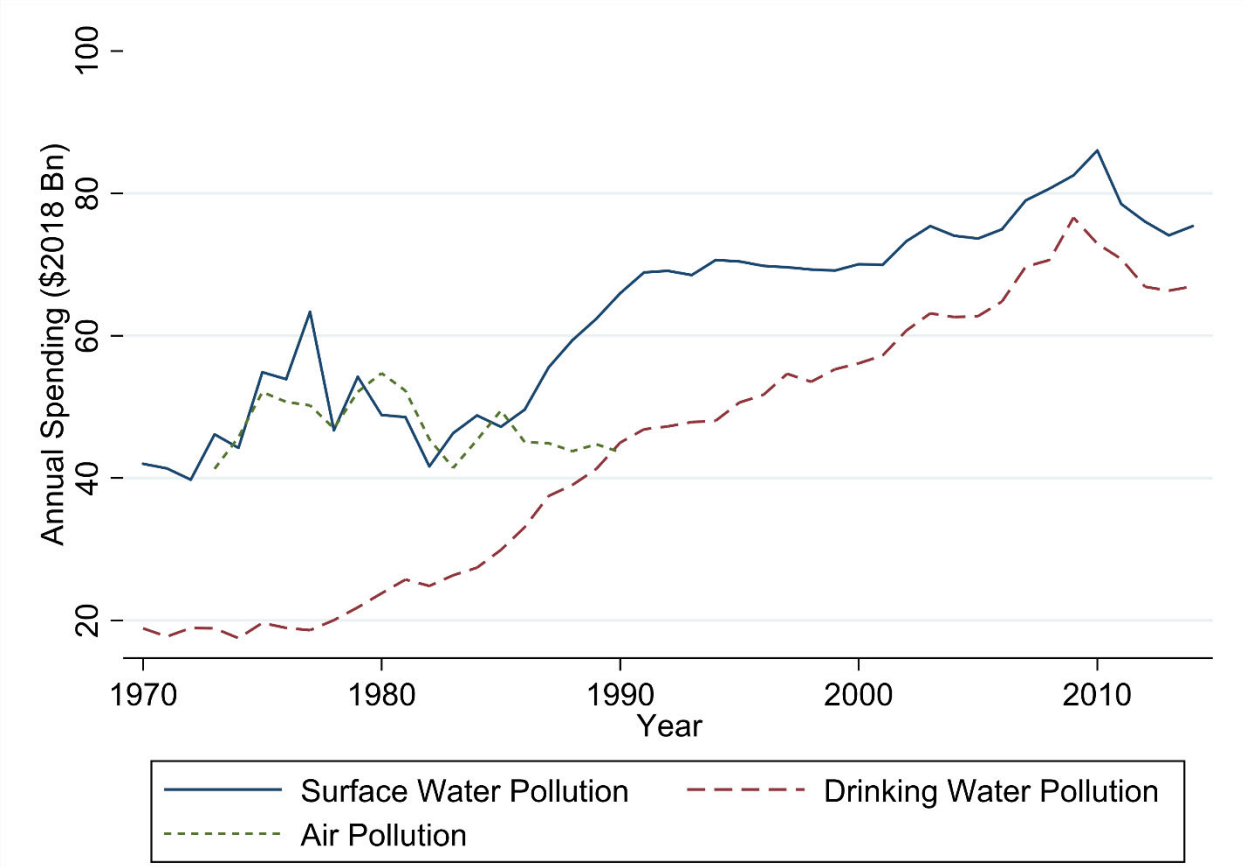
Note: This definition of "fishable" is the most widely used in research; it was developed by William Vaughan for Resources for the Future and reflects published water quality criteria and state water quality standards between 1966 and 1979. Formally, "Fishable" readings have biochemical oxygen demand below 2.4 mg/L, dissolved oxygen above 64% saturation, fecal coliforms below 1,000 MPN/100 mL, and total suspended solids below 50 mg/L. 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% confidence interval, and 1972 is the reference category. Standard errors clustered by watershed. Graph summarizes 14.6 million pollution readings from 265,000 monitoring sites from Storet Legacy, Modern Storet, and the National Water Information System. See Keiser and Shapiro (2019) for details on the data cleaning procedure.

Figure 3
U.S. Drinking Water Quality Violations, 1982-2014



Note: Data from Allaire (2018) and cover a balanced panel of 17,900 community water systems. 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 a health-based standard.

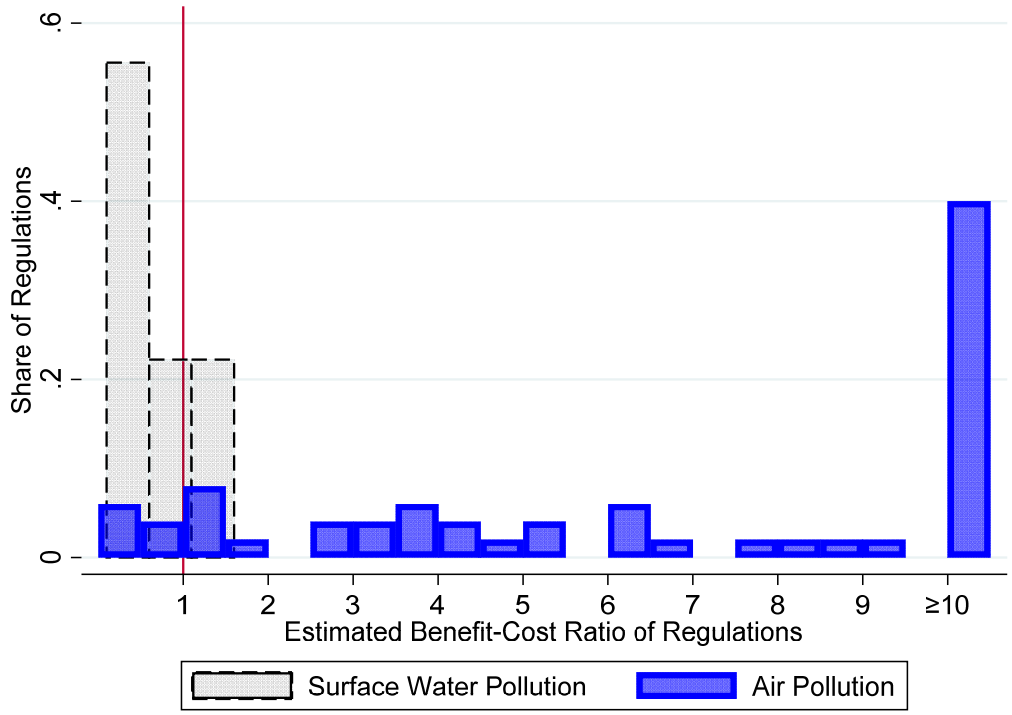
Figure 4
Annual Investments to Clean Pollution in Surface Waters, Drinking Water, and Air, 1970-2010



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

Figure 5

Estimated Benefit-Cost Ratios of Federal Regulations of Air Pollution Versus Surface Water Pollution



Note: Data from "Report to Congress on the Costs and Benefits of Regulations and Unfunded Mandates," various years. See Table 2 for further details.

Table 1

Breakdown of water pollution discharge permits, by industry

	All	Major permits	
	%	%	%, Excluding Sewerage
	(2)	(5)	(6)
Agriculture & Fishing	0.08	0.00	0.01
Mining	0.11	0.02	0.05
Construction	0.13	0.00	0.00
Manufacturing	0.16	0.18	0.55
Transportation	0.04	0.00	0.01
Utilities	0.26	0.76	0.28
Electricity	*0.01*	*0.08*	*0.25*
Sewerage systems	*0.21*	*0.67*	—
Services and nonclassifiable	0.21	0.03	0.10
Total	1.00	1.00	1.00

Note: database includes 136,082 total permits and 6,869 major permits. Data from Permit Compliance System-Integrated Compliance Information System, accessed Feb 12, 2019, at https://www.epa.gov/enviro/pcs-icis-customized-search. Values are total number of observations with standard industrial classification (SIC) codes in the indicated categories. Indented industries are sub-groups. Classifications are as follows: agriculture and fishing (<999); mining (1000-1499); construction (1500-1799); manufacturing (2000-3999); transportation (4000-4599); utilities (4600-4999); electricity (4911); sewerage systems (4952); services and nonclassifiable (5000-9999).

Table 2
Benefits and Costs of Federal Regulations

	Surface Water (1)	*Drinking Water (2)*	*Air (3)*	*Greenhouse Gases (4)*	*All Other (5)*	*All (6)*
Total U.S. Expenditures ($2017 trillion)						
1970 to 2014	$2.83	$1.99	$2.11	—	—	—
1973 to 1990	$0.94	$0.49	$0.85	—	—	—
Regulations Analyzed in Federal Reviews						
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

Note: Column (5) covers all regulations not in columns (1)-(4). 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. For studies which 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% discount rate. When studies present multiple estimates for other reasons, this table averages the multiple estimates. Table includes the few studies which report negative costs (i.e., cost savings). It also includes studies which contain notes that their benefits or costs are incomplete in specific known ways. This table excludes regulations with unreported benefits or unreported costs, or regulations with benefits and costs not reported in monetary terms, or in non-comparable monetary terms. Greenhouse gases includes energy efficiency regulations. For studies listing only a bound (e.g., benefits up to 10 million), this table uses the bound. Regulations affecting emissions from all media (e.g., regulating manufacture and disposal of PCBs) are not listed as air or water policies. Total U.S. Expenditures reflect public and private investments (see Appendix A), and are not readily available for greenhouse gases or all other regulations (columns 4-5).

Table 3
Prevalence of Research on Air Versus Water Pollution

	Type of Pollution			Ratio: Air v. Water	
	Air	Surface Water	Surface or Drinking Water	Air/Surface	Air/(Surface+ Drinking)
	(1)	(2)	(3)	(4)	(5)
Economics journal articles					
All	1243	510	567	2.4	2.2
Year 2000+	599	235	263	2.5	2.3
Top 5 journals	53	3	5	17.7	10.6
Environmental/energy journals	240	157	175	1.5	1.4
Non-economics journal articles					
Environment	1494	1388	2079	1.1	0.7
Health	982	348	984	2.8	1.0
NBER Summer Institute Presentations, 2009-2018	24	3	2	8.0	4.8
Environmental Economics Textbooks # Pages					
Mean	30	15	6	2.0	1.4
Median	22	10	5	2.2	1.5
Public finance textbooks Mean # Pages	4.5	0	0	—	—

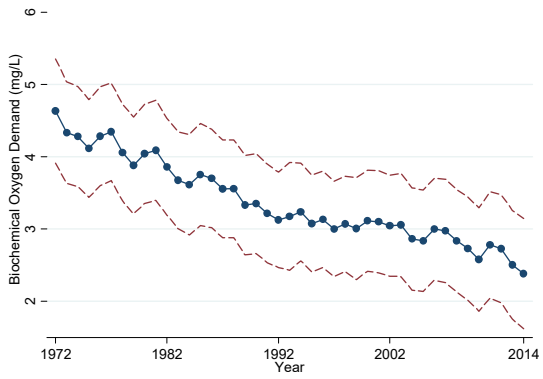
Note: Journal articles are all from JSTOR, and include mentions of "Clean Air Act," ("Clean Water Act" or "Federal Water Pollution Control Act"), or "Safe Drinking Water Act," searched 1/23/2019 and 1/24/2019. Top 5 economics journals includes the American Economic Review (excluding Papers and Proceedings issues), Econometrica, Journal of Political Economy, Quarterly Journal of Economics, and Review of Economic Studies. Environmental/energy journals include American Journal of Agricultural Economics; Climate Change Economics; Economics of Energy & Environmental Policy; The Energy Journal; Environment and Development Economics; the Journal of Agricultural and Resource Economics; the Journal of Energy and Development; the Journal of the Association of Environmental and Resource Economists; Land Economics; and Marine Resource Economics. "Non-economics: environment" includes journals that JSTOR categorizes into environmental science or environmental studies. "Non-economics: health" includes journals that JSTOR categorizes in health policy, health sciences, or public health, excluding the Journal of the American Water Works Association since it is the only journal in these categories not primary focused on health. Including that journal in the health category makes the values in columns (1)-(3) become 1057, 885, and 2866. NBER Summer Institute data includes Environmental and Energy Economics (EEE) sessions. Articles using general pollution sources (Toxic Release Inventory, Superfund sites, total pollution abatement costs) are counted as half each in air and surface water pollution; NBER counts exclude 5-minute ("egg timer") presentations. In textbooks, for air pollution, we counted page mentions in the index of topics starting with the phrases “clean air,” “CAA,” “air pollution,” “air quality,” or “air pollutants,” though excluded references that were clearly to climate change or atmospheric ozone depletion. For water pollution, we counted page mentions starting with the phrases “clean water,” “FWPCA,” “federal water,” “water quality,” “water pollution,” “safe drinking,” “SDWA,” or “drinking water.” It is possible some of the air pollution references are still discussions of climate change, though the imbalance of research towards air is at least as pronounced if we only count references to “Clean Air Act,”

"Clean Water Act," and "Safe Drinking Water Act." The environmental textbooks include Chapman (2000), Goodstein (2002), Berck and Helfand (2011), Kolstad (2011), Callan and Thomas (2013), Anderson and Libecap (2014), Freeman, Herriges, and Kling (2014), and Phaneuf and Requate (2017). The public finance textbooks include Rosen (2002) and Gruber (2011).

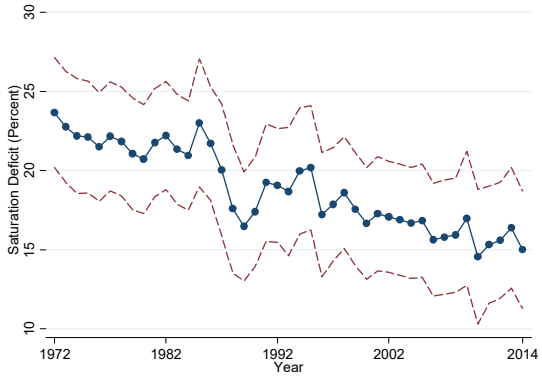
Appendix Figures and Tables

Appendix Figure 1
U.S. Surface Water Pollution Trends, 1972-2014, Additional Pollutants

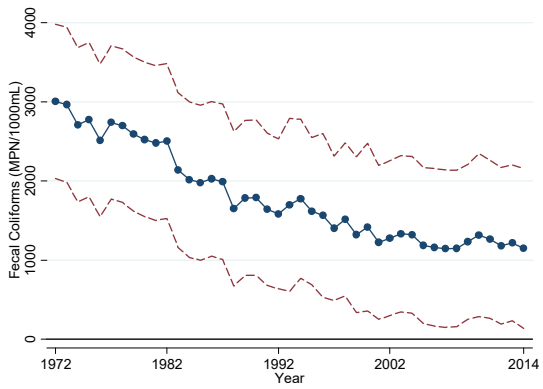
Panel A. Biochemical Oxygen Demand



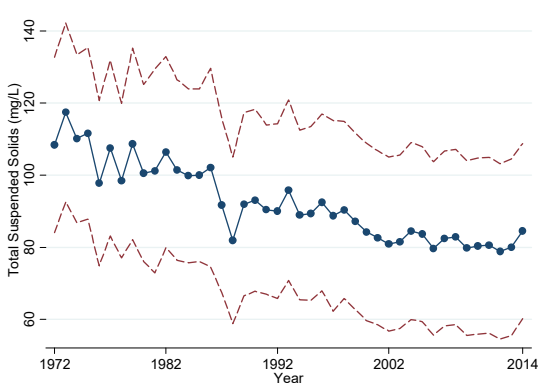
Panel B. Dissolved Oxygen Saturation Deficit



Panel C. Fecal Coliforms



Panel D. Total Suspended Solids



Note: see notes to Figure 2.

Appendix A: Estimates of Spending on Air and Water Pollution Control Programs

This appendix describes available data on the total costs of investments in surface water quality, drinking water treatment, and air pollution abatement. We construct estimates of spending using a number of sources. These include Keiser and Shapiro's (forthcoming) analysis of the Clean Water Act municipal grants program, Keiser, Kling, and Shapiro's (forthcoming) analysis of benefits and costs of surface water quality programs, a Congressional Research Service report on federal appropriations of surface and drinking water programs at US EPA (Copeland 2015), a Congressional Budget Office (2018) report on public spending on transportation and water infrastructure, and a report on local spending on water and wastewater services from the U.S. Conference of Mayors (2010). We also use a number of reports by US EPA detailing costs of the Clean Air Act and Keiser and Shapiro's (forthcoming) analysis of spending on air pollution control programs. Obtaining comprehensive spending estimates in each of these areas faces a number of challenges including incomplete reporting across communities and across time and the potential for double counting of federal, state, and local spending.

This Appendix reports a range of estimates; the main text highlights the best available estimates. We also focus on the period 1970 to 2014 since spending estimates for each of these categories are more complete for this period. We deflate all estimates to $2017 using the Engineering News-Record Construction Cost Index.

Surface Water Quality – Preferred Estimate: $2.8 trillion (range of $1.9 to $3.0 trillion)

Keiser and Shapiro (2019) and Keiser, Kling, and Shapiro (forthcoming) report estimates of spending on surface water quality pollution control programs that are driven primarily by federal policies (i.e, the Clean Water Act's municipal grants program and the Clean Water Act's State Revolving Funds program), industrial spending on water pollution abatement, and nonpoint source programs sponsored by the federal government such as a number of U.S. Department of Agriculture conservation programs.

Federal Spending – Preferred Estimate: $0.6 trillion (range of $0.5 to $0.6 trillion)

To account for federal government funds, we use Keiser and Shapiro's (forthcoming) estimate of spending on grants to local municipalities and net out local matching expenditures on capital, operations, and maintenance costs. We add spending estimates on the federal portion of Clean Water State Revolving Funds (CWSRFs) from Keiser, Kling, and Shapiro (forthcoming). These sources suggest approximately $370 billion in direct federal spending on wastewater treatment. This estimate exceeds Copeland's (2015) estimate of $256 billion in total appropriations for wastewater treatment programs, though Copeland's estimates start in 1973. This estimate also exceeds CBO's (2018) estimate of total federal spending on both wastewater and drinking water treatment ($363 billion). However, Copeland's federal appropriation estimates for drinking water only total $26 billion, which suggests CBO's total estimate is likely largely due to wastewater treatment. Each source suggests similar patterns in funding over time, with much greater amounts in the 1970s. We use the estimates from Keiser and Shapiro (2019) as they reflect estimates of grant spending recovered from US EPA records and Clean Water State Revolving Funds estimates from US EPA.

In addition to these funds, we include spending on non-point source control programs from Keiser, Kling, and Shapiro (forthcoming) that primarily reflect spending on USDA conservation programs. This adds an additional $219 billion. Our preferred estimates for total federal spending on wastewater treatment is thus $589 billion with a range of $475 billion to $589 billion.

Local Spending - Preferred Estimate: $1.6 trillion (range of $0.8 to 1.7 trillion)

Our estimates of local spending on wastewater treatment comes from CBO (2018) and the U.S. Conference of Mayors (2010). We first take annual spending estimates from CBO (2018) that represent state and local spending for infrastructure, net of federal grant and loan subsidies. These estimates represent both wastewater and drinking water spending. To apportion this spending between wastewater and drinking water, we use the U.S. Conference of Mayors (2010) report that provides estimates of the share of local spending by decade between wastewater and drinking water treatment. The CBO (2018) and U.S. Conference of Mayors (2010) estimates of total spending on wastewater and drinking water treatment track each other closely and are based on similar census data. However, the U.S. Conference of Mayors local spending estimates may also reflect federal grants and subsidies. For example, CBO's estimates of federal contributions to wastewater and drinking water total $363 billion. This figure added to CBO's estimate of $3.6 trillion in state and local spending net of federal spending closely approximates the U.S. Conference of Mayors (2010) estimate ($3.92 vs. $3.87 trillion).

Keiser, Kling, and Shapiro (forthcoming) present estimates of local spending tied to federal and state programs (i.e., the Clean Water Act grants and CWSRF). These estimates are broadly similar through 1986 ($251 billion for Keiser, Kling, and Shapiro vs. $348 billion for CBO and the Conference of Mayor estimates). The main divergences occur after 1986, corresponding to a sharp decline in the federal grants program. Since Keiser, Kling, and Shapiro focus on spending tied to federal programs while CBO includes local spending independent of federal grants, the CBO estimate is likely to be more complete.

Our preferred estimate of local spending is thus $1.6 trillion with a range of $801 billion to $1.7 trillion. The Keiser and Shapiro (2019) local estimate reflects our lower bound and the U.S. Conference of Mayors (2010) report reflects our upper bound.

Industrial - Preferred Estimate: $0.6 trillion

Our estimates of industrial spending are based on Keiser and Shapiro (2019) and Keiser, Kling, and Shapiro (forthcoming). These estimates are based on Pollution Abatement Costs and Expenditures (PACE) surveys from 1973 – 1986, 1988 – 1994, and 2005.

Drinking Water Quality – Preferred Estimate: $2.0 trillion (range of $2.0 to $2.2 trillion)

Federal Spending - Preferred Estimate: $26B

We use Copeland's (2015) estimate of federal appropriations for Drinking Water State Revolving Funds, which started in 1997. These total $26B.

Local and State Spending - Preferred Estimate: $1.9 trillion (range of $1.9 to $2.1 trillion)

To estimate local and state spending, we follow a similar protocol for drinking water as for wastewater. We allocate CBO's (2018) estimate of total local spending net of federal contributions based on the U.S. Conference of Mayors (2010) estimate of the share of spending assigned to wastewater versus drinking water. This yields an estimate of $1.9 trillion in local and state spending on drinking water treatment. The U.S. Conference of Mayors (2010) estimates provide a slightly larger figure at $2.1 trillion.

Air Pollution Control – Preferred Estimate: $2.1 trillion (range of $2.1 to 2.7 trillion)

We use EPA's (1997) retrospective analysis of the Clean Air Act as the main source for expenditures on air pollution control. These expenditures represent additional spending due to the Clean Air Act. We do not observe expenditures from before the Clean Air Act, so these estimates may provide a lower bound on total spending. EPA (1997) estimates annual expenditures on compliance costs for 1973 to 1990. For 1970 to 1972, we assume annual expenditures equal expenditures in 1973. While expenditures in 1973 were the lowest of any year, expenditures in real dollars remained fairly steady over this time period ($41.3B in 1973 versus an average of $47.2B per year for 1973 to 1990).

Recovering annual estimates after 1991 is more challenging. Table 2 assumes that annual estimates for 1991 to 2014 equal the average expenditures from 1973 to 1990. This is a strong assumption, since the Clean Air Act Amendments of 1990 may have increased spending. However, a separate prospective study by US EPA for 1990 to 2020 (US EPA 2011) provide similar estimates of total spending over this time period. For example, our cost estimates for 2000 to 2014 are $708 billion, which is roughly similar to estimates of $877 billion from EPA. We construct an upper range estimate given a few of these sources. First, we use EPA's restrospective estimates until 1988. We then assume a jump in costs due to the CAAA that correspond to an increase we observe in the PACE data through 1994. We then assume constant cost estimates constant for 1995 to 2000. For 2001 to 2014, we assume costs increase by the same level of changes as in USEPA (2011). This procedure requires substantial imputation and interpolation, which is why Figure 5 does not show values for these years, and why Table 2 separately reports estimates for years where such imputation is not needed. This yields an upper bound estimate of $2.7 trillion.

Keiser and Shapiro (2019) discuss an additional source of estimates from the Bureau of Economic Analysis for the years 1972 to 1994. These estimates place expenditures on air pollution abatement at $1.1 to $1.6 trillion. Our estimates using the EPA retrospective analysis provide similar estimates over this time period of $1 trillion.

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