CONSEQUENCES OF THE CLEAN WATER ACT AND THE DEMAND FOR WATER QUALITY*

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Abstract

Since the 1972 U.S. Clean Water Act, government and industry have invested over $1 trillion to abate water pollution, or $100 per person-year. Over half of U.S. stream and river miles, however, still violate pollution standards. We use the most comprehensive set of files ever compiled on water pollution and its determinants, including 50 million pollution readings from 240,000 monitoring sites and a network model of all U.S. rivers, to study water pollution's trends, causes, and welfare consequences. We have three main findings. First, water pollution concentrations have fallen substantially. Between 1972 and 2001, for example, the share of waters safe for fishing grew by 12 percentage points. Second, the Clean Water Act's grants to municipal wastewater treatment plants, which account for $650 billion in expenditure, caused some of these declines. Through these grants, it cost around $1.5 million (2014 dollars) to make one river-mile fishable for a year. We find little displacement of municipal expenditure due to a federal grant. Third, the grants' estimated effects on housing values are smaller than the grants' costs; we carefully discuss welfare implications. JEL Codes: H23, H54, H70, Q50, R31.

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I Introduction

The 1972 U.S. Clean Water Act sought "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This paper quantifies changes in water pollution since before 1972, studies the causes of any changes, and analyzes the welfare consequences of any changes.

The Clean Water Act addressed a classic externality. Textbooks since at least Stigler (1952; 1966) have illustrated the concept of an externality through the story of a plant dumping waste in a river and harming people downstream. The immediate impetus for the Clean Water Act was a 1969 fire on the Cuyahoga River, which had fires every decade since 1868 though has had no fires since 1972. Time (1969) described it vividly:

> "Anyone who falls into the Cuyahoga does not drown," Cleveland's citizens joke grimly. "He decays." The Federal Water Pollution Control Administration dryly notes: "The lower Cuyahoga has no visible life, not even low forms such as leeches and sludge worms that usually thrive on wastes. It is also literally a fire hazard."

Despite the potential to address this market failure, the Clean Water Act has been one of the most controversial regulations in U.S. history, for at least two reasons. First, it is unclear whether the Clean Water Act has been effective, or whether water pollution has decreased at all. An analysis in the 1990s summarized, "As we approached the twenty-year anniversary of this landmark law, no comprehensive analysis was available to answer basic questions: How much cleaner are our rivers than they were two decades ago?" (Adler, Landman and Cameron 1993). Other writers echo these sentiments (Knopman and Smith 1993; Powell 1995; Harrington 2004). Today over half of U.S. river and stream miles violate state water quality standards (USEPA 2016), but it is not known if water quality was even worse before the Clean Water Act. William Ruckelshaus, the first head of the U.S. Environmental Protection Agency (EPA), nicely summarized what *is* known about water pollution today: "even if all of our waters are not swimmable or fishable, at least they are not flammable" (Mehan III 2010).

The second controversy is whether the Clean Water Act's benefits have exceeded its costs, which have been enormous. Since 1972, government and industry have spent over $1 trillion to abate water pollution, or over $100 per person-year. This is more than the U.S. has spent on air pollution abatement (see Appendix A). In the mid-1970s, Clean Water Act funding of municipal wastewater treatment plants

was the single largest public works program in the U.S. (USEPA 1975). These costs were large partly because the Clean Water Act had ambitious targets: to make **all** U.S. waters fishable and swimmable by 1983; to have **zero** water pollution discharge by 1985; and to prohibit discharge of toxic amounts of toxic pollutants. President Nixon actually vetoed the Clean Water Act and described its costs as "unconscionable," though Congress later overruled the veto (Nixon 1972). Large costs could be outweighed by large benefits. However, existing cost-benefit analyses of the Clean Water Act have not estimated positive benefit/cost ratios (Lyon and Farrow 1995; Freeman III 2000), including U.S. Environmental Protection Agency's own retrospective analysis (2000a; 2000c).

These academic controversies have spilled over into politics. The U.S. Supreme Court's 2001 and 2006 *SWANCC* and *Rapanos* decisions removed Clean Water Act regulation for nearly half of U.S. rivers and streams. In 2015, the Obama Administration proposed a Clean Water Rule (also called the Waters of the United States Rule) which would reinstate many of those regulations. Twenty-seven states have sued to vacate the rule.

This paper seeks to shed light on these controversies using the most comprehensive set of files ever compiled in academia or government on water pollution and its determinants. These files include several datasets that largely have not been used in economic research, including the National Hydrography Dataset, which is a georeferenced atlas mapping all U.S. surface waters; the Clean Watershed Needs Survey, which is a panel description of the country's wastewater treatment plants; a historic extract of the Grants Information and Control System describing each of 35,000 Clean Water Act grants the federal government gave cities; the Survey of Water Use in Manufacturing, a confidential plant-level dataset of large industrial water users which was recently recovered from a decommissioned government mainframe (Becker 2016); and around 50 million water pollution readings at over 240,000 pollution monitoring sites during the years 1962-2001 from three data repositories—Storet Legacy, Modern Storet and the National Water Information System (NWIS). Discovering, obtaining, and compiling these data has been a serious undertaking involving three Freedom of Information Act requests, detailed analysis of hydrological routing models, and extensive discussions with engineers and hydrologists from the U.S. Geological Survey (USGS), the EPA, and engineering consultancies. These data enable a more extensive analysis of water pollution and its regulation than has previously been possible.

The analysis obtains three sets of results. First, we find that most types of water pollution declined

over the period 1962-2001, though the rate of decrease slowed over time. Between 1972 and 2001, the share of waters that met standards for fishing grew by 12 percentage points. The pH of rivers and lakes has increased at a similar rate to the pH of rainwater, likely in part due to decreased sulfur air pollution. In other words, less acid rain may have led to less acidic rivers and lakes. Additionally, the temperature of rivers and lakes increased by 1 degree F every 40 years, consistent with climate change.

Second, the paper asks how the Clean Water Act's grants to municipal wastewater treatment plants, one of the Act's central components, contributed to these trends. We answer this question using a triple-difference research design comparing water pollution before versus after investments occurred, upstream versus downstream of recipient plants, and across plants. We define upstream and downstream waters using a set of 70 million nodes that collectively describe the entire U.S. river network. We find that each grant decreases the probability that downriver areas violate standards for being fishable by half a percentage point. These changes are concentrated within 25 miles downstream of the treatment plant and they persist for 30 years. Through these grants, it cost around $1.5 million ($2014) per year to make one river-mile fishable. We do not find substantial heterogeneity in cost-effectiveness across regions or types of grants. We also find that one dollar of a federal grant project led to about one additional dollar of municipal sewerage capital spending.

Third, the paper asks how residents valued these grants. We analyze housing units within a 25 mile radius of affected river segments, partly since 95 percent of recreational trips have a destination within this distance. We find that a grant's estimated effects on home values are about 25 percent of the grant's costs. While the average grant project in our analysis cost around $31 million ($2014), our main estimates imply that the estimated effect of a grant on the value of housing within 25 miles of the affected river is around $7 million. We find limited heterogeneity in these numbers across regions and types of grants.

We discuss several reasons why the true benefit/cost ratio for the grants program could exceed this 0.25 ratio of the change in home values to grant costs. These reasons include that people may have incomplete information about changes in water pollution and their welfare (including health) implications; these numbers exclude nonuse ("existence") values; grants may increase sewer fees; these estimates abstract from general equilibrium effects; and they exclude the five percent of most distant recreational trips. Available evidence to evaluate these reasons is limited; it does suggest that the true benefit/cost ratio may exceed 0.25, though does not clearly show that this ratio exceeds one. One interpretation of our

main estimates is that the benefits of these grants exceed their costs if these unmeasured components of willingness to pay exceed the components of willingness to pay that we measure by a factor of three or more.

We provide several indirect tests of the identifying assumptions, which generally support the validity of the research design. First, we report event study graphs in time which test for pre-trends in the years preceding a grant. Second, we report two research designs—a triple-difference estimator which uses upstream areas as a counterfactual for downstream areas, and a differences-in-differences estimate using only downstream areas. Third, we assess whether grants affect pollutants closely related to municipal waste more than they affect pollutants that are less closely related. Fourth, we separately estimate the effect of a plant receiving one, two, three, or more grants. Finally, we estimate specifications controlling for important potential confounding variables, including industrial water pollution sources, air pollution regulations, and local population totals.

More broadly, this paper departs from the literature in four primary ways. This is the first study quantifying national changes in water pollution since before the Clean Water Act using a dense network of monitoring sites. Trends are important in their own right and because measuring water pollution is a step towards measuring its costs (Muller, Mendelsohn and Nordhaus 2011). Some studies measure trends in water pollution for small sets of monitoring sites (e.g., USEPA 2000b; Smith, Alexander and Wolman 1987).[1]

This paper also provides the first national estimate of how Clean Water Act investments affected ambient pollution concentrations. We use these estimates to calculate the cost effectiveness of these investments. Water pollution research typically uses ex ante engineering simulations to assess water quality policies (Wu et al. 2004). A few studies do investigate how water pollution affects self-reported emissions of one pollutant in specific settings (Earnhart 2004a,b; Cohen and Keiser 2017), or study similar questions for air pollution (Shapiro and Walker Forthcoming). Recent research finds that India's water pollution regulations, which have similar structure to the U.S. Clean Water Act, are ineffective (Ebenstein 2012; Greenstone and Hanna 2014). Several studies find that ambient water pollution increases

[1] Smith and Wolloh (2012) study one measure of pollution (dissolved oxygen) in lakes beginning after the Clean Water Act and use data from one of the repositories we analyze. They conclude that "nothing has changed" since 1975. We find similar trends for the pollutant they study in lakes, though we show that other pollutants are declining in lakes and that most pollutants are declining in other types of waters.

with political boundaries (Sigman 2002; Lipscomb and Mobarak 2017; Kahn, Li and Zhao 2015). Some work investigates how fracking wells and the pollution they send to wastewater treatment plants affect water quality (Olmstead et al. 2013).

Third, this study provides the first estimate of the effects of water pollution regulation on home values. Existing estimates of willingness-to-pay for water quality use travel cost methods, hedonics, or stated preferences (i.e., contingent valuation; Kuwayama and Olmstead (2015) list many individual studies).[2] Travel cost studies typically rely on cross-sectional variation in pollution and focus on a limited area like a county (e.g., Smith and Desvousges 1986), though some work uses broader coverage (Keiser Forthcoming). Such studies may suffer from omitted variable bias because unobserved disamenities like factories or roads contribute to pollution and discourage recreational visits (Leggett and Bockstael 2000; Murdock 2006; Moeltner and von Haefen 2011). Such omitted variables are important for studying air pollution, though their importance for water pollution is unknown. Most cost-benefit analyses of the Clean Water Act rely on stated preferences (Carson and Mitchell 1993; Lyon and Farrow 1995; USEPA 2000a), which are controversial (Hausman 2012; Kling, Phaneuf and Zhao 2012; McFadden and Train 2017).

Finally, we believe this is the first empirical study of the efficiency of subsidizing the use of pollution control equipment. This policy is common in many countries and settings. Theoretical research has lamented the poor incentives of such subsidies (Kohn 1992; Aidt 1998; Fredriksson 1998) and empirical research is scarce.[3] Our analysis of heterogeneity in cost-effectiveness and benefit-cost ratios also provides a new domain to consider recent research on spatially differentiated policy (Muller and Mendelsohn 2009).

The paper proceeds as follows. Section II describes the Clean Water Act and water pollution. Section III explains the data. Section IV discusses the econometric and economic models. Section V summarizes pollution trends. Section VI analyzes how grants affected pollution. Section VII discusses grants' effects on housing. Section VIII concludes. All appendix material appears in the online appendix.

[2] Muehlenbachs, Spiller and Timmins (2015) relate fracking to home values and drinking water. Some studies in historic or developing country settings, where drinking water regulation is limited, relate surface water quality to health (Ebenstein 2012; Greenstone and Hanna 2014; Alsan and Goldin Forthcoming). Others relate drinking water quality directly to health (Currie et al. 2013).

[3] The only econometric analysis we know of such policies tests how the French policy of jointly taxing industrial air pollution and subsidizing abatement technologies affected emissions, using data from 226 plants (Millock and Nauges 2006). That study does not separately identify the effect of the pollution tax from the effect of the abatement subsidy.

II The Clean Water Act and Water Pollution

II.A Clean Water Act Background

Policies before the Clean Water Act may contribute to some of the water pollution patterns we observe before 1972.[4] The U.S. Congress passed major water pollution control laws in 1948, 1956, 1961, 1965, 1966, and 1970. Many earlier laws, like the Clean Water Act, supported municipal wastewater treatment and industrial abatement, but provided funds an order of magnitude below the funds distributed by the Clean Water Act. By 1966, all 50 states had passed some type of water pollution legislation, but enforcement varied greatly across states (Hines 1967).

The Clean Water Act retained large roles for state-level implementation, and the effectiveness of that implementation most likely varied across states. While a simple formula determined the level of grant funds that each state received, each state designed the priority lists determining which plants received grants. States with decentralized authority also oversaw writing of permits for municipal plants, monitoring and enforcement of violations, and other activities (Sigman 2003, 2005).

The Clean Water Act targeted municipal waste treatment and industrial pollution sources, sometimes called "point sources." However, much water pollution also comes from "non-point" pollution sources such as urban and agricultural runoff. The Clean Water Act has largely exempted these latter sources from regulation.

This paper focuses on the Clean Water Act grants program, but the Clean Water Act also limited industrial water pollution through the National Pollutant Discharge Elimination System (NPDES). NPDES aims to cover every source which directly discharges pollution into U.S. waters. Some plants are part of a separate "Pretreatment Program," in which they discharge untreated or lightly-treated wastewater through sewers to wastewater treatment plants, then pay fees to the treatment plant.[5] The permits were distributed in the early 1970s. This was a national program affecting most plants and industries at around the same time.

[4] The 1972 law was formally called the Federal Water Pollution Control Amendments, though we follow common practice in referring to it as the Clean Water Act.

[5] The wastewater treatment plants which are the focus of this paper also receive effluent permits through the NPDES program, so our analysis of grants may also reflect NPDES permits distributed to wastewater treatment plants.

II.B Wastewater Treatment Background

In most cities and towns, sewers convey wastewater to a municipal wastewater treatment plant which treats the waste and then discharges it to surface waters. Ninety-eight percent of treatment plants are publicly owned (USEPA 2002). The abatement technology in treatment plants initially only included screens to remove large objects. As technology improved during the twentieth century, treatment plants began allowing wastewater to settle before discharging, then plants began applying biological treatments (e.g., bacteria) that degrade pollution, and finally began using more advanced chemical treatments. These abatement technologies are generally called raw, primary, secondary, and tertiary treatment. The Clean Water Act required all municipal treatment plants to have at least secondary treatment by 1977.

This investment in wastewater treatment was not cheap. Projects funded by Clean Water Act grants cost about $650 billion in total over their lifetimes ($2014). Grants covered new treatment plants, improvement of existing plants, and upgrades to sewers (USEPA 1975). Local governments paid about a fourth of most grant projects' capital costs.[6] The 1987 Clean Water Act Amendments replaced these grants with subsidized loans (the Clean Water State Revolving Fund).

The U.S. did not come close to meeting the Clean Water Act's goal of having every plant install secondary treatment by 1977, though abatement technologies improved over time. In 1978, for example, nearly a third of all plants lacked secondary treatment, and by 1996, almost none did. The treatment technology used in wastewater treatment plants, however, had been improving steadily before the Clean Water Act (USEPA 2000b).

Because this paper exploits the timing and location of grants to identify the effect of the Clean Water Act's grants program, it is useful to clarify how grants were distributed. The allocation of wastewater spending across states came from formulas depending on state population, forecast population, and wastewater treatment needs (CBO 1985). Within a state, grants were distributed according to a "priority list" that each state submitted annually to the EPA. States had to base a priority list on seven criteria (USEPA 1980, p. 8):

[6] The federal government paid 75 percent of the capital cost for most construction projects awarded through September 1984, and 55 percent thereafter; local governments paid the rest of the capital costs. Beginning in 1977, grants provided a higher 85 percent subsidy to projects using "innovative" technology, such as those sending wastewater through constructed wetlands for treatment. This extra subsidy fell to 75 percent in 1984, and about 8 percent of projects received the subsidy for innovative technology (USGAO 1994).

> 1. [T]he severity of the pollution problem; 2. [T]he existing population affected; 3. [T]he need for preservation of high quality waters; 4. [A]t the State's option, the specific category of need... 5. ... [T]echniques meeting innovative and alternative guidelines... 6. [O]ther criteria, consistent with these, may be considered (including the special needs of small and rural communities). The state may not consider: the project area's development needs not related to pollution abatement; the geographical region within the State; or future population growth projections; and 7. [I]n addition to the criteria listed above, the State must consider ... total funds available; and other management criteria.

EPA estimated that it took two to ten years from project conception to finishing construction.

II.C Water Pollution Background

This paper emphasizes two measures of water quality – the dissolved oxygen saturation of water, and whether waters are fishable – though also reports results for other measures. We focus on dissolved oxygen saturation because it is among the most common omnibus measures of water quality in research, because it responds to a wide variety of pollutants, and because it is a continuous (rather than binary) measure of pollution, which alleviates concerns about failing to measure inframarginal changes in water quality. Most aquatic life requires dissolved oxygen to survive. Water can absorb dissolved oxygen from the air, but loses dissolved oxygen when microorganisms consume oxygen in order to decompose pollution. Dissolved oxygen levels move inversely with temperature. Dissolved oxygen saturation represents the dissolved oxygen level divided by the maximum oxygen level expected given the water temperature, so implicitly adjusts for water temperature. Actual dissolved oxygen saturation is bounded below at zero (describing water with no oxygen) but is not bounded above. Dissolved oxygen deficits are defined as 100 minus dissolved oxygen saturation.

We focus also on the fishable standard because making water safe for fishing is a major goal of the Clean Water Act, and because recreational fishing is believed to be a main reason why people value water quality. We use a definition of "fishable" developed by William Vaughan for Resources for the Future (RFF). This definition distills several published water quality criteria and state water quality standards from between 1966 and 1979. It is also a widely-used interpretation of "fishable." In this definition,

water is "fishable" if pollution is below a threshold, based on four measures: biochemical oxygen demand (BOD), dissolved oxygen saturation, fecal coliforms, and total suspended solids (TSS). To implement these definitions in the data, we pool data from these pollutants and define a dummy for whether a raw pollution reading exceeds the relevant standard.[7]

We also report estimates for whether waters are swimmable, and we report separate results for the other pollutants that are part of the "fishable" and "swimmable" definitions—BOD, fecal coliforms, and TSS. These pollutants merit interest in their own right because BOD, fecal coliforms, and TSS are a majority of the five "conventional pollutants" the Clean Water Act targeted. The other "conventional" pollutants are pH, which we analyze in Appendix Table IV, and oil and grease, a pollutant for which we have little data. We define all pollutants so that lower levels of the pollutant represent cleaner water (so we report the share of waters that are "not fishable" or "not swimmable," and we report dissolved oxygen deficits).

Describing these other pollutants may help interpret results. BOD measures the amount of oxygen consumed by decomposing organic matter. Fecal coliforms proxy for the presence of pathogenic bacteria, viruses, and protozoa like E. coli that cause human illness. Pathogens including fecal coliforms are the most common reason why water quality violates state standards today (USEPA 2016). TSS measures the quantity of solids in water that is trapped by a filter.[8] Municipal sources in the early 1980s were estimated to account for about 20 percent of national BOD emissions and less than one percent of national TSS emissions (Gianessi and Peskin 1981), though municipal sources may account for a larger share of emissions in urban areas. Most TSS comes from agriculture and urban runoff.

We also report a few results for three additional groups of pollutants: industrial pollutants like lead, mercury, and phenols; nutrients like nitrogen and phosphorus; and other general water quality measures like temperature. We use a standardized criterion, described in Appendix B.3, to choose pollutants for

[7] "Fishable" readings have BOD below 2.4 mg/L, dissolved oxygen above 64 percent saturation (equivalently, dissolved oxygen deficits below 36 percent), fecal coliforms below 1000 MPN/100mL, and TSS below 50 mg/L. "Swimmable" waters must have BOD below 1.5 mg/L, dissolved oxygen above 83 percent saturation (equivalently, dissolved oxygen deficits below 17 percent), fecal coliforms below 200 MPN/100mL, and TSS below 10 mg/L. The definition also includes standards for boating and drinking water that we do not analyze.

[8] We analyze all these physical pollutants in levels, though Appendix Tables III and VI show results also in logs. Fecal coliforms are approximately lognormally distributed, and BOD and TSS are somewhat skewed (Appendix Figure I). Log specifications would implicitly assume that the percentage change in a river's pollution due to a grant is the same for a river with a high background concentration, which is unlikely. Other water pollution research generally specifies BOD and TSS in levels; practices vary for fecal coliforms.

this appendix table.

One important question is how far these pollutants travel downstream. We focus on a distance of 25 miles for several reasons. First, the only engineering study we found on this question (USEPA 2001) limited its analysis to 25 miles downstream of point sources for BOD. They chose this distance to reflect 15 watershed-specific studies designed to remedy pollution problems. Second, an interview with a wastewater regulation specialist at the Iowa Department of Natural Resources suggested that effects of treatment plants on dissolved oxygen would be concentrated within 20 miles downriver. Third, estimated effects of grants on whether rivers are fishable out to 100 miles downstream of a treatment plant only show effects within 25 miles (Appendix Table VI).

III Data

We use eight types of data; Appendix B provides additional details.

1. Spatial Data on Rivers and Lakes. We use data from the National Hydrography Dataset Plus, Version 2.1 (NHD), an electronic atlas mapping all U.S. surface waters. NHD organizes the U.S. into approximately 200 river basins, 2,000 watersheds, 70,000 named rivers, 3.5 million stream and river miles, and 70 million river nodes. A river in these data consists of a set of river nodes (i.e., points) connected by straight lines. NHD forms a network describing the flow direction of each river or stream segment and helps us follow water pollution upstream or downstream. Panel A of Figure I shows U.S. streams, rivers, and lakes, colored by their distance from the ocean, Great Lakes, or other terminus. (See details in Appendix B.2.)

2. Municipal Water Pollution Sources. We use data on U.S. municipal water pollution treatment plants from the EPA's Clean Watershed Needs Survey (CWNS). We use latitude and longitude data from the first available year for a plant (CWNS reports this beginning in 1984), and grant identifying codes for all available years. We limit the analysis to plants that report non-zero population served.

3. Clean Water Act Grants. We filed two Freedom of Information Act requests to obtain details on each of the 35,000 Clean Water Act grants that the federal government gave to these plants. These records come from the EPA's Grants Information and Control System (GICS). We restrict the analysis to grants with non-missing award date, grant amount, and total project cost (including both federal and

local capital expenditures). The data also report the name of the overseeing government authority (city, county, state, or special district), a grant identifier code, and the name of the recipient treatment plant. The data also include grants in the years 1957-1971 given under predecessor laws to the Clean Water Act. For simplicity, the analysis counts multiple grants to a treatment plant in a calendar year as a single grant. (See details in Appendix B.4.)

4. Ambient Levels of Water Pollution. We use water pollution readings from three federal data repositories: Storet Legacy, Modern Storet, and the National Water Information System (NWIS).[9] Storet Legacy focuses on the earlier part of our period, and the full raw data include 18,000 data files and 200 million pollution readings. Modern Storet is similar to Storet Legacy but covers more recent years. The Storet repositories have data from many local organizations. USGS national and state offices collect a large share of NWIS readings. Appendix B.3 describes details and steps taken to clean these data, including limiting to rivers, streams, or lakes, restricting to comparable measurement methods, winsorizing at the 99th percentile, excluding readings specific to hurricanes and other non-routine events, and others.

Appendix Table I provides basic descriptive statistics. The analysis sample includes 11 million observations on the four main pollutants and 38 million observations on the additional pollutants discussed in Appendix Table IV. The analysis sample covers 180,000 monitoring sites; an additional 60,000 monitoring sites record data on the other pollutants discussed in Appendix Table IV. Levels of BOD, fecal coliforms, and dissolved oxygen deficits are much lower in the U.S. than in India or China (Greenstone and Hanna, 2014). Among the four main pollutants, about half the data describe dissolved oxygen. Almost half the data come from monitoring sites that report readings in at least three of the four decades we analyze.

No sampling design explains why certain areas and years were monitored more than others. In some cases, hydrologists purposefully designed representative samples of U.S. waters. At least three such networks are in these data: the Hydrologic Benchmark Network, the National Stream Quality Accounting Network, and the National Water-Quality Assessment Program (HBN, NASQAN, and NAWQA), which this paper discusses later. In other cases, sampling locations and frequency were chosen by local governments or non-governmental organizations. Cities and some states like Massachusetts have denser

[9] We considered a fourth repository, the Sustaining the Earth's Watersheds: Agricultural Research Data System (STEWARDS), managed by the USDA. We did not use these data because they focus on years 1990 and later, mainly measure pesticides, and have a small sample.

monitoring networks, while other areas like Texas have less dense networks (Figure I, Panel C).

5. Census Tract Data. We use the Geolytics Neighborhood Change Database (NCDB), which Geolytics built from the 1970, 1980, 1990, and 2000 Censuses of Population and Housing. The 1970 census only included metro areas in tracts, so these tract-level data for 1970 are restricted to metro areas, and so much of our analysis is as well.

We use these census data because they have national coverage and because transaction-level records from county assessor offices, such as those aggregated by Dataquick or CoreLogic, generally do not extend back to the 1970s. Appendix B.5 provides further details, including a discussion of data quality.

6. Recreational Travel Distances. We seek to determine a distance around a river that covers most individuals who travel to participate in recreation at this river. We obtain estimates of this distance from the Nationwide Personal Transportation Survey (NPTS) for years 1983, 1990, and 1995. This survey is the only source we know that provides a large nationally representative sample of recreational activities and travel distances over the period we study.[10] The survey picks a day and has respondents list all trips, their purposes, and the driving distances in miles. We limit trip purposes to "vacation" or "other social or recreation." Averaged across the three survey years, the 95th percentile of one-way distance from home to recreational destinations is about 34 miles. Of course, these data represent all recreational trips, and do not distinguish whether water-based recreation trips require different travel distances.

This is the distance traveled along roads, but the radius we use to calculate the distance of homes from rivers represents the shortest direct path along the ground ("great circle distance"). We are aware of two comparisons between great circle and road distances. First, the 2009 National Household Travel Survey (USDOT 2009, successor to the NPTS) reports both the road and great circle distance between a person's home and the person's workplace. The mean ratio of the road distance to the great circle distance is 1.4. Second, a recent study compared driving distance versus great circle distances for travel from a representative sample of 70,000 locations in the U.S. to the nearest community hospital, and the average ratio was also 1.4 (Boscoe, Henry and Zdeb 2012).[11] So we estimate that the great circle distance between homes and rivers which covers 95 percent of recreational trips is 25 miles ($\approx$33.7/1.4).

[10] The National Survey of Recreation and the Environment and its predecessor, the National Recreation Survey, do not systematically summarize trips taken and travel distances. Many travel demand papers use small surveys that report distance traveled to a specific lake or for a narrow region.

[11] The 1.4 ratio and the 34 mile calculation from the previous paragraph both use survey weights. These values are similar without survey weights, or when excluding outlier reported travel distances (above 150 miles).

7. Municipal Financial Records. To examine the pass-through of federal Clean Water Act grants to municipal spending on wastewater treatment, we use data from the 1970-2001 Annual Survey of State and Local Government Finances and the Census of Governments. These data report annual capital and total expenditures for sewerage (a category including wastewater treatment), separately for each local government.[12] The final sample includes 198 cities; in addition to describing these data in more detail, Appendix B.6 discusses the main sample restrictions, including requiring a balanced panel and accurate links to the grants data. Given this sample size, we report a set of estimates which weight by the inverse propensity score, to provide estimates more representative of all cities. For use as a control variable in some specifications, we obtain population data for most of these cities from the 1970-2000 decennial censuses, then linearly interpolate between years.

8. Other Environmental Data. One sensitivity analysis controls for nearby industrial sources of water pollution. We are not aware of any complete data on industrial water pollution sources around the year 1972, so we use two distinct controls as imperfect proxies. The first is a list of the manufacturing plants that used large amounts of water in 1972. We obtain these data from the confidential 1973 Survey of Water Use in Manufacturing (SWUM) microdata, accessed through a Census Research Data Center. The second control is a count of the cumulative number of plants in a county holding industrial effluent (NPDES) permits. We filed a Freedom of Information Act request to obtain a historic copy of the EPA database which keeps records of industrial pollution sources—the Permit Compliance System, now called the Integrated Compliance Information System. Appendix B.7 describes more information on these sources, along with additional data on weather and nonattainment designations. Finally, Appendix B.8 describes data used to consider heterogeneity across different groups of grants by several dimensions: grant size, baseline abatement technologies, baseline pollution, Clean Water Act state decentralization, prevalence of local outdoor fishing and swimming, local environmental views, declining older urban areas (Glaeser and Gyourko 2005), and high amenity areas (Albouy 2016).

Spatial Links. We construct four types of links between datasets. The first involves linking each pollution monitoring site and treatment plant to the associated river or lake. The second involves measuring distances along rivers between treatment plants and pollution monitoring sites. The third involves

[12] The "year" in these data refers to each local government's fiscal year. We convert the data to calendar years using data from these surveys on the month when each government's fiscal year ends, assuming that government expenditure is evenly distributed across months. For the few governments that don't report when their fiscal year ends, we assume they report by calendar year.

measuring areas of census tracts around rivers. The fourth involves linking grants to individual plants in the CWNS. Appendix C provides details of each step.

IV Econometric and Economic Models

IV.A Econometrics: Water Pollution Trends

We use the following equation to assess year-by-year changes in water pollution:

$$Q_{icy} = \sum_{\tau=1963}^{\tau=2001} \alpha_\tau 1[y_y = \tau] + X_{icy}^{'}\beta + \delta_i + \epsilon_{icy} \tag{1}$$

Each observation in this analysis is an individual water pollution reading at monitoring site i, hour and calendar day-of-year c, and year y. The variable Q_{icy} represents the level of water pollution. We estimate this equation separately for each pollutant. The matrix X_{icy} includes cubic polynomials in time of day and in day of year. In sensitivity analyses, X_{icy} also includes air temperature and precipitation. The fixed effects δ_i control for all time-invariant determinants of water pollution specific to monitoring site i. These are important because they adjust for any cross-sectional differences in baseline pollution rates across monitoring sites in the imbalanced panel, which ensures that identification comes only from changes in pollution within each monitoring site and over time. The error term ϵ_{icy} includes other determinants of water pollution. We plot the year-by-year coefficients $\alpha_{1963} \ldots \alpha_{2001}$ plus the constant. The year-specific points in graphs can be interpreted as mean national patterns of water pollution, controlling for time and monitoring site characteristics.

Except where otherwise noted, all regressions in the paper are clustered by watershed. Appendix Tables III, VI, and VIII also report results from two-way clustering by watershed and year. A watershed is defined by the USGS as an area of land in which all water within it drains to one point. Where relevant, watersheds or counties are defined by the treatment plant's location.

We also estimate linear water pollution trends using the following equation:

$$Q_{icy} = \alpha y_y + X_{icy}^{'}\beta + \delta_i + \epsilon_{icy} \tag{2}$$

The main coefficient of interest, α, represents the mean annual change in water pollution, conditional on the other controls in the regression. We also show specifications which interact the trend term y with an indicator $1[y \geq 1972]$ for whether an observation is year 1972 or later. This interaction measures how water pollution trends differed after versus before the Clean Water Act. We emphasize graphs based on equation (1) more than tables based on equation (2) since the nonlinear trends in graphs are crudely approximated with linear trends and since 30 years is a long post period.

IV.B Econometrics: Effects of Grants on Water Pollution

This section discusses estimates of how grants affect downstream water pollution, which is the paper's second main research question. It then assesses how grants affect municipal spending on wastewater treatment capital. Appendix D discusses evidence on how water pollution changes as rivers pass treatment plants, which tests the hypothesis that the data capture an important feature of the world.

Effects of Clean Water Act Grants on Water Pollution

We use the following regression to estimate effects of Clean Water Act grants on water pollution:

$$Q_{pdy} = \gamma G_{py} d_d + X_{pdy}^{'} \beta + \eta_{pd} + \eta_{py} + \eta_{dwy} + \epsilon_{pdy} \tag{3}$$

This regression has two observations for each treatment plant p and year y, one observation describing mean water quality upstream ($d = 0$), and the other observation describing mean water quality downstream ($d = 1$). The variable G_{py} describes the cumulative number of grants that plant p had received by year y. This regression measures grants as a cumulative stock because they represent investment in durable capital. The main coefficient of interest, γ, represents the mean effect of each grant on downstream water pollution. We also explore other specifications for G, including limiting to grants for construction and not for planning or design, estimating effects separately for each possible number of cumulative grants, and others.

Equation (3) includes several important sets of controls. The matrix X_{pdy} includes temperature and precipitation controls. The plant×downstream fixed effects η_{pd} allow both upstream and downstream waters for each treatment plant to have different mean levels of water pollution. These fixed effects

control for time-invariant sources of pollution like factories and farms, which may be only upstream or only downstream of a plant. The plant×year fixed effects η_{py} allow for water pollution to differ near each treatment plant in each year, and they control for forces like the growth of local industries, other environmental regulations, and changes in population density which affect both upstream and downstream pollution. The downstream×basin×year fixed effects η_{dwy} allow upstream and downstream water quality separately to differ by year in ways that are common to all plants in a river basin. These fixed effects address the possibility that other point source pollutants and regulations are located near wastewater treatment plants and had water quality trends related to the municipal grants.

Equation (3) focuses on the effect of the number of grants a plant has received, rather than the dollar value of these grants, for several reasons. (Appendix Table VI reports similar effects of grant dollars.) First, it may be easier to think in discrete terms about the effect of a grant, rather than the effect of an arbitrary amount of money. Second, estimating these regressions in simple discrete terms makes the regression tables more easily comparable with event study graphs. Third, larger grants tend to go to more populated areas and larger rivers. Because it takes larger investment to achieve a change in pollution concentration for a more populated area and larger river, it is ambiguous whether larger grants should have larger effects on pollution concentrations. Fourth, the distribution of cumulative grant amounts is both skewed and has many zeros. Focusing on the number of grants rather than grant dollars avoids issues involved in log transformations (or other approaches) in the presence of many zeros.

A few other details are worth noting. Because the dependent variable is an average over different numbers of underlying pollution readings, in all regressions where each observation is plant-downstream-year tuple, we use generalized least squares weighted by the number of raw underlying pollution readings.[13] To maximize comparability between the treatment plant location and monitoring sites, we restrict pollution data to monitoring sites located on the same river as the treatment plant. Finally, estimates are limited to plants within 1 kilometer of a river node. Appendix Table VI shows results with some of these assumptions relaxed.

The identifying assumption for equation (3) to provide an unbiased estimate of the parameter γ is

[13] We also report unweighted estimates. GLS based on the number of underlying pollution readings in each plant×downstream×year is an efficient response to heteroskedasticity since we have grouped data. GLS estimates the effect for the average pollution reading rather than for the average plant×downstream×year. It is possible that areas with more pollution data may be of greater interest; for example, Panel C of Figure I shows more monitoring sites in more populated areas.

that the grants×downstream interaction $G_{py}d$ is independent of the regression error, conditional on other explanatory variables:

$$E[G_{py}d_d \cdot \epsilon_{dpy}|X_{pdy}, \eta_{pd}, \eta_{py}, \eta_{dwy}] = 0$$

This assumption would be violated if, for example, grants or permits responded to unobserved shocks to variables like population which themselves affect pollution concentrations.[14]

We also report event study graphs of outcomes relative to the year when a facility receives a grant:[15]

$$Q_{pdy} = \sum_{\tau=-10}^{\tau=25} \gamma_\tau 1[G_{p,y+\tau} = 1]d_d + X'_{pdy}\beta + \eta_{pd} + \eta_{py} + \eta_{dwy} + \epsilon_{pdy} \tag{4}$$

Here τ indexes years since a grant was received, where $\tau = -10$ is plants receiving a grant ten or more years in the future, and $\tau = -25$ is plants receiving grants 25 or more years in the past.[16]

Pass-through of Clean Water Act Grants to Municipal Expenditure

How does a dollar of Clean Water Act grants affect municipal spending on wastewater treatment? Grants could have complete pass-through, so a federal grant of one dollar increases municipal spending on wastewater treatment by a dollar. Grants could also have incomplete pass-through (crowding out municipal expenditure) or more than complete pass-through (crowding in).

We study this question primarily because it can increase the accuracy of cost-effectiveness and cost-benefit analyses. If, for example an additional dollar of federal grant funds lead cities to spend less than a dollar on wastewater treatment, then the spending due to grants is less than our cost data imply.

[14] This assumption could also fail if changes in governments' effectiveness at receiving grants are correlated with governments' effectiveness at operating treatment plants. This does not seem consistent with our results since it would likely create pre-trends in pollution or home values, whereas we observe none. Our finding that benefits last about as long as engineering estimates suggest (30 years) and for only the expected pollutants also are not exactly what this story would predict. We also observe that each additional grant results in further decreases in pollution (Appendix Table VI), which would be a complicated story for the timing of government human capital to explain.

[15] The analysis includes plants that never received a grant (which have all event study indicators $1[G_{p,y+\tau} = 1]$ equal to zero), plants that received a single grant (which in any observation have only a single event indicator equal to one), and plants that received more than one grant (which in any observation can have several event indicators equal to one). Since no reference category is required in this kind of event study setting where one observation can receive multiple treatments, for ease of interpretation, we recenter the graph line so the coefficient for the year before treatment ($\tau - 1$) equals zero. This implies that coefficients in the graph can be interpreted as the pollution level in a given year, relative to the pollution level in the period before the treatment plant received a grant.

[16] As in most event study analyses, only a subset of event study indicators are observed for all grants. Because most grants were given in the 1970s, we observe water pollution up to 10 years before and 15-25 years after most grants.

The question of how federal grants affect municipal spending is also important in the fiscal federalism literature (Oates 1999; Lutz 2010). Finally, this analysis provides some evidence on the quality of the grants data, since the grants data come from a completely different source than the municipal expenditure data.

To estimate the pass-through of Clean Water Act grants to local expenditure, we regress cumulative municipal sewerage capital expenditures E_{cy} in city c and year y on cumulative Clean Water Act grant dollars D_{cy} this city has received:

$$E_{cy} = \beta D_{cy} + \upsilon_c + \eta_{wy} + \epsilon_{cy} \tag{5}$$

The dependent and independent variables are cumulative because capital is a stock, and since local investment could occur after the grants are received. The regression includes city fixed effects υ_c and year fixed effects η_y. We also report specifications with river basin×year fixed effects η_{wy}. The value $\beta = 1$ implies complete pass-through (no crowding out or crowding in). Finding $\beta < 1$ implies incomplete pass-through (crowding out), while $\beta > 1$ implies more than complete pass-through (crowding in).

The definitions of these variables are important. Municipal expenditures E_{cy} include both expenditures funded by federal grants and those funded by other sources of revenue. As mentioned in Section II.B, most grants require cities to pay 25 percent of the capital cost, though a small share require other copayments. We therefore report two sets of regressions—one where the variable D_{cy} includes only federal grant funds, and another where the variable D_{cy} includes both federal grant funds and the required municipal capital contribution. We also report specifications that weight by the inverse propensity score for inclusion in the balanced panel of cities.

IV.C Demand for Water Quality

Hedonic Model

A few definitions and a graph convey essential features of the hedonic model. A house i is described by a vector of its J different characteristics, $(z_1, \ldots, z_J)$. The home's price is $P_i = P(z_1, \ldots, z_J)$. The marginal implicit price of attribute j is the marginal change in home price due to a marginal increase in attribute j, all else constant: $P_{z_j} \equiv \partial P / \partial z_j$. The key feature of this hedonic price schedule $P(\cdot)$ is that

it reflects the equilibrium of firms that supply housing and consumers that demand housing. We assume that housing markets are competitive and that each consumer rents one house.

Appendix Figure VII illustrates. The curve θ_1 describes the bid function of one type of consumer. The bid function is the consumer's indifference curve in the tradeoff between the price of a home and the amount of attribute j embodied in the home. The curve θ_2 describes the bid function for another type of consumer. The curve ϕ_1 describes the offer function of a firm, and ϕ_2 of another firm. The offer function is the firm's isoprofit curve in the tradeoff between home price and attribute j.

The hedonic price schedule provides information about willingness-to-pay for amenity j because it reflects the points of tangency between consumer bid curves and firm offer curves. This implies that the marginal implicit price of an amenity at a given point on the hedonic price schedule equals the marginal willingness to pay of the consumer who locates on that point of the hedonic price schedule.

Econometrics: Demand for Water Quality

To analyze how Clean Water Act grants affected home values, we use a differences-in-differences estimate comparing the change in the log mean value of homes within a 0.25, 1, or 25 mile radius in any direction of the downstream river, before versus after the plant receives a grant, and between plants receiving grants in early versus late years.

Because water pollution flows in a known direction, areas upstream of a treatment plant provide a natural counterfactual for areas downstream of a plant. For this reason, our preferred methodology in Section IV.B to assess how Clean Water Act grants affect water pollution uses a triple-difference estimator comparing upstream and downstream areas. But because residents who live upstream of treatment plants can benefit from clean water downstream of treatment plants (e.g., by traveling for recreation), upstream homes could benefit from grants. Hence our preferred housing estimates come from difference-in-difference regressions analyzing homes within a 25 mile radius of river segments that are downstream of treatment plants. We report both the double-difference and triple-difference estimators for both outcomes, and obtain qualitatively similar conclusions.

We estimate the following regression:

$$V_{py} = \gamma G_{py} + X_{py}^{'}\beta + \eta_p + \eta_{wy} + \epsilon_{py} \tag{6}$$

Here G_{py} represents the cumulative number of grants received by plant p in year y, V_{py} is the log mean value of homes within a 0.25, 1, or 25 mile radius of the portion of the river that is 25 miles downstream of treatment plant p, η_p are plant fixed effects, and η_{wy} are river basin×year fixed effects. Some specifications include controls X_{py} for house structure characteristics and the interaction of baseline characteristics with year fixed effects (see Appendix B.5 for details). We estimate the change in total housing units and total value of the housing stock.

A few points are worth noting. First, we limit regression estimates to the set of tracts reporting home values in all four years 1970, 1980, 1990, 2000. When we fit the change in home values, we do so both for only the balanced panel of tract-years reporting home values, and for all tract-years. Second, because the differences-in-differences specification used for home values does not use upstream areas as a counterfactual, it involves the stronger identifying assumption that areas with more and fewer grants would have had similar home price trends in the absence of the grants. In part for this reason, we focus on specifications including basin×year fixed effects and the interaction of baseline characteristics with year fixed effects. Estimates without the basin×year controls are more positive but also more sensitive to specification, which is one indication that the specification of equation (6) provides sharper identification. Fourth, to obtain regression estimates for the average housing unit, and to provide an efficient response to heteroskedasticity, we include generalized least squares weights proportional to the number of total housing units in the plant-year observation and to the sampling probability.[17]

V Water Pollution Trends

V.A Main Results

We find large declines in most pollutants the Clean Water Act targeted. Dissolved oxygen deficits and the share of waters that are not fishable both decreased almost every year between 1962 and 1990 (Figure II). After 1990, the trends approach zero. Year-by-year trends for the other pollutants in the main analysis – the share of waters that are not swimmable, BOD, fecal coliforms, and TSS – show similar patterns (Appendix Figure III).

[17]The census long form has housing data and was collected from one in six households on average, but the exact proportion sampled varies across tracts.

The graphs show no obvious evidence of a mean-shift or trend-break in water pollution around 1972. This tells us little about the Clean Water Act's effects, however, since its investments may take time to affect water pollution, expanded during the 1970s, and may be effective even if not obvious from a national time series. These graphs also suggest that existing evaluations of the Clean Water Act, which typically consist of national trend reports based on data from after 1972, may reflect forces other than the Clean Water Act. Using a national time series to evaluate the Clean Water Act could imply that it has been counterproductive, since the rate of decrease in pollution slowed after 1972.

Regressions with linear trend and trend break specifications underscore these findings, subject to the caveats mentioned earlier about the linear approximations and the long post period. The share of waters that are not fishable fell on average by about half a percentage point per year, and the share that are not swimmable fell at a similar rate (Table I, Panel A). In total over the period 1972-2001, the share of waters that are not fishable and the share not swimmable fell by 11 to 12 percentage points. Each of the four pollutants which are part of these fishable and swimmable definitions declined rapidly during this period. Fecal coliforms had the fastest rate of decrease, at 2.5 percent per year. BOD, dissolved oxygen deficits, and total suspended solids all declined at 1 to 2 percent per year.

These full data show more rapid declines before 1972 than after it. Independent evidence is generally consistent with this idea. Engineering calculations in USEPA (2000b) suggest that the efficiency with which treatment plants removed pollution grew faster in the 1960s than in the 1980s or 1990s. Hines (1967) describes state and local control of water pollution in the 1960s, which typically included legislation designating regulated waters and water quality standards, a state pollution control board, and enforcement powers against polluters including fines and incarceration. Data on industrial water pollution in the 1960s is less detailed, though manufacturing water intake (which is highly correlated with pollution emissions) was flat between 1964 and 1973 due to increasing internal recycling of water (Becker 2016). Moreover, the share of industrial water discharge that was treated by some abatement technology grew substantially in the 1960s (U.S. Census Bureau 1971). We interpret pre-1972 trends cautiously, however, both because far fewer monitoring sites recorded data before the 1970s (Appendix Table I), and because the higher-quality monitoring networks (NAWQA, NASQAN, and HBN) focused their data collection after 1972.

It is interesting to consider possible explanations for these slowing trends. One involves declining

returns to abatement of pollution from "point sources." At the same time, much oxygen-demanding pollution comes from agriculture and other "non-point" sources, and those sources have remained largely unregulated. Another is that "fishable" and "swimmable" are limited between 0 and 1, and dissolved oxygen saturation does not much exceed 100 percent. This explanation is less relevant for the slowing trends in continuous variables like BOD, fecal coliforms, or TSS.

We estimate many sensitivity analyses, including restricting to high-quality subsamples of the data, adding important controls, weighting by population, and many others. Most of these alternative approaches have similar sign, magnitude, and precision as the main results. Appendix Table III shows these results and Appendix E.1 explains each.

V.B Other Water Quality Measures

We also discuss trends in three other groups of water quality measures: industrial pollutants; nutrients; and general measures of water quality (Appendix Table IV).[18] All three industrial pollutants have declined rapidly. Lead's decrease of about 10 percent per year may be related to air pollution regulations, such as prohibiting leaded gasoline. The decline in mercury is noteworthy given the recent controversy of the Mercury and Air Toxics Standards (MATS) policy that would regulate mercury from coal-fired power plants. Some nutrients like ammonia and phosphorus are declining, while others like nitrates are unchanged. Nutrients were not targeted in the original Clean Water Act, but are a focus of current regulation. Temperature is increasing by about 1 degree F per 40 years, which is consistent with effects from climate change. Electricity generating units and other sources do contribute to thermal pollution in rivers, but increasing temperature is an outlier from decreasing trends in most other water pollutants.

pH increased by 0.007 pH units per year, meaning that waters became more basic (less acidic). Rainwater monitors that are not in our data record increases of similar magnitude in rainwater pH over this period, and attribute it to declines in atmospheric sulfur air pollution (USEPA 2007). Hence decreases in acidic sulfur air pollution may have contributed to decreases in acidic water pollution.

[18] Appendix B.3 describes the rule we use to choose indicators for this list; it mainly reflects the pollutants used in the EPA's (1974) first major water pollution report after the Clean Water Act.

VI Clean Water Act Grants and Water Pollution

VI.A Effects of Clean Water Act Grants on Pollution

Table II shows that these grants cause large and statistically significant decreases in pollution. Each grant decreases dissolved oxygen deficits by 0.7 percentage points, and decreases the probability that downstream waters are not fishable by 0.7 percentage points. The other pollutants decrease as well — BOD falls by about 2.4 percent, fecal coliforms fall by 3.6 percent, and the probability that downstream waters are not swimmable by about half a percentage point. The point estimate implies that each grant decreases TSS by one percent, though is imprecise.

Event study graphs corresponding to equation (4) support these results. In years before a grant, the coefficients are statistically indistinguishable from zero, have modest magnitude, and have no clear trend (Figure III). This implies that pollution levels in upstream and downstream waters had similar trends before grants were received. In the years after a grant, downstream waters have 1-2 percent lower dissolved oxygen deficits, and become 1-2 percent less likely to violate fishing standards. These effects grow in magnitude over the first ten years, are statistically significant in this period, and remain negative for about 30 years after a grant. The gradual effect of the grants is unsurprising since, as mentioned earlier, EPA estimates that it took two to ten years after a grant was received for construction to finish. The 30-year duration of these benefits is also consistent with, though on the lower end of, engineering predictions. Two studies report that concrete structures of treatment plants are expected to have a useful life of 50 years but mechanical and electrical components have a useful life of 15-25 years (American Society of Civil Engineers 2011, p. 15; USEPA 2002, p. 11). Event study graphs for other pollutants are consistent with these results, though are less precise (Appendix Figure IV). Appendix Figure V shows the effect of a grant by distance downstream from a treatment plant; less data is available to estimate effects separately for each 5-mile bin along the river, and estimates are correspondingly less precise.

Appendix Table VI shows a variety of sensitivity analyses, and Appendix E.2 discusses each. They give similar qualitative conclusions as the main results, though exact point estimates vary.

VI.B Grants' Effects on Water Pollution: Cost-Effectiveness

We now turn to estimate the cost-effectiveness of these grants. The cost-effectiveness is defined as the annual public expenditure required to decrease dissolved oxygen deficits in a river-mile by 10 percentage points or to make a river-mile fishable. These calculations use our regression estimates and the cost data.

Even without the hedonic estimates of the next section, one can combine cost-effectiveness numbers with estimates from other studies of the value of clean waters to obtain a cost-benefit analysis of these grants. Moreover, we are not aware of any existing ex post estimates of the cost required to make a river-mile fishable or to decrease dissolved oxygen deficits.

Table III presents estimates of cost-effectiveness. The simplest specification of column (1), which includes rivers with water quality data, implies that it cost \$0.67 million per year to increase dissolved oxygen saturation in a river-mile by ten percent; the broadest specification of column (3), which assumes every treatment plant has 25 miles of downstream waters affected, implies that it cost \$0.53 million per year. The annual cost to make a river-mile fishable ranges from \$1.5 to \$1.9 million.[19]

A few notes are important for interpreting these statistics. First, this is the average cost to supply water quality via Clean Water Act grants; the marginal cost, or the cost for a specific river, may differ. Second, measuring cost-effectiveness is insufficient to reach conclusions about social welfare; Section VII discusses peoples' value for these changes. Third, if some grant expenditures were lost to rents (e.g., corruption), then those expenditures represent transfers and not true economic costs. EPA did audit grants to minimize malfeasance. In the presence of such rents, this analysis could be interpreted as a cost-effectiveness analysis from the government's perspective.

Appendix E.2 investigates heterogeneity in grants' effects on water pollution and cost-effectiveness. Overall, this evidence does not suggest dramatic heterogeneity in cost-effectiveness. Compared to the mean grant, grants to declining urban areas are significantly less cost-effective, while grants to the generally rural counties where many people go fishing or swimming are significantly more effective. Most others are statistically indistinguishable from the mean grant, though there is some moderate (if statistically insignificant) heterogeneity in point estimates.

[19]The cost-effectiveness estimates for fishable regressions are based on Appendix Table VI, Row 13. The main regression estimates in Table II reflect the change in the share of pollution readings that are fishable and do not distinguish between cases where the share of readings that are fishable moved from 20 to 21 percent, or where it changed from 80 to 81 percent. The statistic we use reflects the binary cutoff of whether a majority of readings are fishable.

VI.C Pass-Through of Clean Water Act Grants to Municipal Expenditure

Table IV reports estimates corresponding to equation (5). In Panel A, the main explanatory variable excludes required municipal contributions, while Panel B includes them. Column (1) reports a basic differences-in-differences regression with nominal dollars. Column (2) uses real dollars. A city may spend a grant in years after it is received, so real pass-through may be lower than nominal pass-through. Column (3) adds river basin×year fixed effects. Column (4) reweights estimates using the inverse of the estimated propensity score for inclusion in the balanced panel of cities.

The estimates in Table IV are generally consistent with near complete pass-through, i.e., little or no crowding out or in beyond the required municipal capital copayment. Panel A estimates pass-through modestly above one since it excludes the required municipal copayment. Panel B includes the local copayment, and finds pass-through rates of 0.84 to 0.93 in real terms or 1.09 in nominal terms. These estimates are within a standard deviation of one, so fail to reject the hypothesis that the municipal wastewater investment exactly equals the cost listed in the grant project data.[20]

We emphasize a few caveats in interpreting Table IV. First, the analysis is based on only 198 cities. The inverse propensity score reweighted estimates are designed to reflect the entire population of US cities. Second, this city-level difference-in-difference estimate cannot use the upstream-downstream comparison for identification. Third, this analysis is different from the question of what municipal spending (and pollution and home values) would be in a world without the Clean Water Act. Our estimates are consistent with no crowdout for an individual grant, but the existence of the Clean Water Act may decrease aggregate municipal investment in wastewater treatment. Appendix Figure VI shows national trends in federal versus state and local spending on wastewater treatment capital over the years 1960-1983.[21] State and local spending on wastewater treatment capital declined steadily from a total of $43 billion in 1963 to $22 billion in 1971 and then to $7 billion annually by the late 1970s. Notably, almost half of this decline in state and local wastewater treatment capital spending occurred before the Clean

[20] We also explored estimates controlling for city-year population or city-year municipal revenue. These controls could help address possible omitted variables bias due to city growth in these differences-in-differences regressions, but are potentially a case of bad controls (Angrist and Pischke 2009) since they could be affected by grants. Adding population or city revenue controls to the specification of column (4) in Table IV gives estimates of 1.22 (0.30) or 0.91 (0.18) for Panel A, and 0.92 (0.22) or 0.68 (0.13) for Panel B. We discuss a range of pass-through estimates including these for cost-effectiveness and cost-benefit analysis.

[21] CBO (1985) dictates this time period since it provides the national total state and local spending data underlying this graph.

Water Act. Federal spending grew to between $10 and $20 billion per year in the late 1970s.

Other sources note that these time series trends are consistent with aggregate crowdout (Jondrow and Levy 1984; CBO 1985). Identification from a national time series is difficult, since other national shocks like the 1973-5 and early 1980s recessions, high inflation and interest rates, and the OPEC crisis make the 1960s a poor counterfactual for the 1970s and 1980s.

Our interpretation is that once the Clean Water Act began, cities became less likely to spend municipal funds on wastewater treatment capital. In this sense, the existence of the Clean Water Act did crowd out aggregate municipal investment in wastewater treatment. But municipal investments that occurred were closely connected to grants, and point estimates imply that the grant costs in our data accurately represent the actual change in spending. Appendix E.2 discusses how cost-effectiveness numbers change with alternative estimates of crowd-out.[22]

These pass-through estimates also speak to the broader "flypaper" literature in public finance, a literature named to reflect its finding that federal government spending "sticks where it hits." Researchers have estimated the pass-through of federal grants to local expenditure in education, social assistance, and other public services. A review of ten U.S. studies found pass-through estimates between 0.25 and 1.06 (Hines and Thaler 1995). Non-U.S. studies and more recent U.S. estimates find an even wider range (Gamkhar and Shah 2007). One general conclusion from this literature is that the effect of federal grants on local government expenditure substantially exceeds the effect of local income changes on local government expenditure (the latter is typically around 0.10). This literature also finds that federal grants which require local matching funds and which specify the grants' purpose, both characteristics of the Clean Water Act grants, tend to have higher pass-through rates. Our findings are consistent with both these general conclusions.

VII Demand for Water Quality

VII.A Main Results

Table V analyzes how Clean Water Act grants affect housing. Column (1) shows estimates for homes within a quarter mile of downstream waters. Column (2) adds controls for dwelling characteristics, and

[22] See Kline and Walters (2016) for a related analysis in education.

for baseline covariates interacted with year fixed effects. Column (3) include all homes within 1 mile, and column (4) includes homes within 25 miles.

Panel A reports estimates of how grants affect log mean home values. The positive coefficients in the richer specifications of columns (2) through (4) are consistent with increases in home values, though most are statistically insignificant. Column (4) implies that each grant increases mean home values within 25 miles of affected waters by two and a half hundredths of a percentage point. The 0.25 or 1.0 mile estimates are slightly larger, which is consistent with the idea that residents nearer to the river benefit more from water quality. Panel B analyzes how grants affect log mean rental values. These estimates are even less positive than the estimates for housing. The estimate in column (4), including homes within a 25 mile radius of downstream rivers, is small and statistically insignificant but actually negative.

Panels A and B reflect the classic hedonic model, with fixed housing stock. Panel C estimates the effect of grants on log housing units and Panel D on the log of the total value of the housing stock. They suggest similar conclusions as Panels A and B. Most of these estimates are small and actually negative. Two are marginally significant (Panel C, column 1), though the precision and point estimate diminish with the controls of column (2).

Figure IV shows event study graphs, which suggest similar conclusions as these regressions. Panel A shows modest evidence that in the years after a plant receives a grant, the values of homes within 0.25 miles of the downstream river increase. The increases are small and statistically insignificant in most years. Panel B shows no evidence that homes within 25 miles of the downstream river increase after a treatment plant receives a grant.

We also report a range of sensitivity analyses, which are broadly in line with the main results. Estimates appear in Appendix Table VIII and discussion appears in Appendix E.3.

VII.B Measured Benefits and Costs

We now compare the ratio of a grant's effect on housing values (its "measured benefits") to its costs. The change in the value of housing is estimated by combining the regression estimates of Table V with the baseline value of housing and rents from the census. Grant costs include local and federal capital expenditures plus operating and maintenance costs over the 30 year lifespan for which we estimate grants affect water pollution. We deflate operating and maintenance costs and rents at a rate of 7.85 percent

(Peiser and Smith 1985).[23]

Column (1) of Table VI includes only owned homes within a 1 mile radius of the downstream river segments; column (2) includes homes within a 25 mile radius; and column (3) adds rental units. Column (4) includes imputed home values for the non-metro areas that were not in 1970 or 1980 census.[24]

Considering all owner-occupied homes within 25 miles of the river, the estimated ratio of the grants' aggregate effects on home values to the grants' costs is 0.26. Adding rental units in column (3) barely changes this estimate. The main regression sample includes only a balanced panel of tracts that appear in all four censuses between 1970-2000; imputing values for missing homes hardly changes the ratio in column (4). These confidence regions do not reject the hypothesis that the ratio of the change in home values to the grants' costs is zero but do reject the hypothesis that the change in home values equals the grants' costs.

Appendix Table VII investigates heterogeneity in measured benefits and costs; Appendix E.3 discusses the results. We find suggestive evidence that ratios of measured benefits to costs follow sensible patterns, though not all estimates are precise. None of these subsets of grants considered has a ratio of measured benefits to costs above one, though many of the confidence regions cannot reject a ratio of one. The largest ratios of estimated benefits to costs are for areas where outdoor fishing or swimming is common (ratio of 0.53), for high amenity urban areas (ratio of 0.40), and in the South (ratio of 0.84).

The map in Appendix Figure VIII shows heterogeneity in the ratio of measured benefits to costs across U.S. counties. This map assumes the same hedonic price function and reflects spatial heterogeneity in housing unit density.[25] The map shows that the ratio of measured benefits to costs is larger in more populated counties. The bottom decile of counties, for example, includes ratios of measured benefits to costs of below 0.01. The top decile of counties includes ratios between 0.31 and 0.41. Grants and population are both skewed, so large shares of both are in the top decile. While a point estimate of 0.41 for the ratio of benefits to costs does not exceed one, one should interpret this value in light of the

[23] We include all capital and operating and maintenance costs in the measure of total grant project costs. The tables separately list the different components of costs, and Section VII.C discusses possible effects of these costs on local taxes or fees. We calculate the present value of rental payouts as $rentalPayout[1-(1+r)^{-n}]/r$, where $rentalPayout$ is the change in total annual rents due to the grants, $r = 0.0785$ is the interest rate, and $n = 30$ is the duration of the benefits in years.

[24] We impute these values from a panel regression of log mean home values on year fixed effects and tract fixed effects.

[25] These estimates divide treatment plants into ten deciles of the number of housing units in the year 2000 within 25 miles of downstream river segments. They then use the regression estimates from column 4 of Table V to calculate the ratio of the change in the value of housing and grant costs, separately by decile. Finally, we average this ratio across plants in each county.

discussion from the next subsection that it may be a lower bound on true benefits.

This predictable spatial variation in the net benefits of water quality variation suggests that allowing the stringency of regulation to vary over space may give it greater net benefits (Muller and Mendelsohn 2009; Fowlie and Muller Forthcoming).

VII.C Interpreting Hedonic Estimates

We now discuss six reasons why the ratios of measured benefits to costs from the previous subsection may provide a lower bound on the true benefit/cost ratio. Appendix F discusses other reasons which we believe have weaker support.

First, people might have incomplete information about changes in water pollution and their welfare implications. Research does find statistically significant though imperfect correlation between perceived local water pollution and objectively measured local water pollution (Faulkner et al. 2001; Poor et al. 2001; Jeon et al. 2011; Steinwender, Gundacker and Wittmann 2008; Artell, Ahtiainen and Pouta 2013). Incomplete information would be especially important if pollution abatement improves health. Misperception would be less important if most benefits of surface water quality accrue through recreation or aesthetics, since failing to perceive water pollution through any means would mean its effects on recreational demand are limited. Most recent cost-benefit analyses of the Clean Water Act estimate that a substantial share of benefits come from recreation and aesthetics channels (Lyon and Farrow 1995; Freeman III 2000; USEPA 2000a). Cropper and Oates (1992) describe the Clean Water Act as the only major environmental regulation of the 1970s and 1980s which does not have health as its primary goal.

Second, due to "nonuse" or "existence" values, a person may value a clean river even if that person never visits or lives near that river. We recognize both the potential importance of nonuse values for clean surface waters and the severe challenges in accurately measuring these values.[26] Other categories potentially not measured here include the value for commercial fisheries, industrial water supplies, lower treatment costs for drinking water, and safer drinking water.[27] Evidence on the existence and magnitude

[26]The USEPA's (2000a) cost-benefit analysis of the Clean Water Act estimates that nonuse values are a sixth as large as use values. This analysis, however, is subject to serious concerns about both use and non-use estimates in the underlying studies.

[27]Flint, Michigan, has recently had high lead levels in drinking water due to switching its water source from the Detroit River to the Flint River. Flint potentially could have prevented these problems by adding corrosion inhibitors (like orthophosphate), which are used in many cities including the Detroit water that Flint previously used, at low cost. Drinking water treatment falls under a separate set of regulations, the Safe Drinking Water Act.

of the benefits from these other channels is limited, though as mentioned above, recreation and aesthetics are believed to account for a large majority of the benefits of clean surface waters.

Third, these grants could lead to increased city taxes, sewer fees, or other local costs that depress home values. Table VI separately lists three types of costs: federal expenditures on capital, local expenditures on capital, and operation and maintenance costs. The ultimate entity responsible for local capital costs and operation and maintenance costs is ambiguous since local governments may receive other payments from state or federal governments to help cover these costs. But if local governments ultimately pay these costs, they could depress home values.

A few pieces of evidence help evaluate the relevance of these issues. One is to estimate hedonic regressions excluding housing units in the same city as the wastewater treatment plant. This is potentially informative since increased taxes, sewer fees, or changes in other municipal expenditures are likely to be concentrated in the municipal authority managing the treatment plant, whereas the change in water quality is relevant for areas further downstream. Row 12 of Appendix Table VIII reports this specification and finds similar and if anything slightly less positive change in home values than the main results estimate, which is the opposite of what one would expect if city taxes, sewer fees, or other local costs depressed home values. Another test comes from the fact that the 1980-2000 gross rent data reported in the census include utilities costs. If sewer fees were particularly important, then one would expect rents to increase more than home values do; if anything, the estimates of Table V suggest the opposite. Finally, we can recalculate the ratios in Table VI considering only subsets of costs. The ratio of the change in housing values to federal capital costs in columns (2)-(4) of Table VI ranges from 0.8 to 0.9; the ratio of the change in housing values to the sum of federal capital costs and operating costs (but excluding local capital costs) in these columns is around 0.3. None of these ratios exceeds one, though they are closer to one than are the values in Table VI.

Fourth, this analysis abstracts from general equilibrium changes. One possible channel is that wages change to reflect the improvement in amenities (Roback 1982). A second general equilibrium channel is that the hedonic price function may have shifted. In the presence of such general equilibrium changes, our estimates could be interpreted as a lower bound on willingness to pay (Banzhaf 2015).

Other possible general equilibrium channels describe reasons why the effects of cleaning up an entire river system could differ from summing up the effects of site-specific cleanups. One such channel involves

substitution—cleaning up part of a river in an area with many dirty rivers might have different value than cleaning up a river in an area with many clean rivers. Another possible channel involves ecology. The health of many aquatic species (so indirectly, the benefit people derive from a river) may depend nonlinearly on the area of clean water. Our approach focuses on the effects of cleaning up an individual site and is not as well suited to capture the potentially distinct effects of cleaning up entire river systems.

Fifth, the 25 mile radius is only designed to capture 95 percent of recreational trips. The last 5 percent of trips might account for disproportionate surplus because they represent people willing to travel great distances for recreation. Alternatively, the most distant travelers might be marginal. Our recreation data also represent all trips, and water-based recreation trips might require different travel distances.

Finally, we interpret our pass-through estimates cautiously since they reflect only 198 cities, do not use upstream waters as a comparison group, and reflect pass-through of marginal changes in investment, rather than the entire Clean Water Act. Appendix E.3 discusses interpretations of our housing estimates under alternative pass-through numbers.

VIII Conclusions

This paper assembles an array of new data to assess water pollution's trends, causes, and welfare consequences. We find that by most measures, U.S. water pollution has declined since 1972, though some evidence suggests it may have declined at a faster rate before 1972. The share of waters that are fishable has grown by 12 percentage points since the Clean Water Act.

We study $650 billion in expenditure due to 35,000 grants the federal government gave cities to improve wastewater treatment plants. Each grant significantly decreased pollution for 25 miles downstream, and these benefits last for around 30 years. We find weak evidence that local residents value these grants, though estimates of increases in housing values are generally smaller than costs of grant projects.

Our estimated ratio of the change in housing costs to total grant costs may provide a lower bound on the true benefit/cost ratio of this grant program since we abstract from nonuse ("existence") values, general equilibrium effects, potential changes in sewer fees, and the roughly five percent longest recreational trips. The point estimates imply that the benefits of the Clean Water Act's municipal grants exceed their costs if these unmeasured components of willingness to pay are three or more times the components

of willingness to pay that we measure. As mentioned in the introduction, other recent analyses estimate benefits of the Clean Water Act that are smaller than its costs, though these other estimates note that they may also provide a lower bound on benefits. For example, the U.S. Environmental Projection Agency's (2000a; 2000c) estimate of the benefit/cost ratio of the Clean Water Act is below 1, though the EPA's preferred estimate of the benefit/cost ratio of the Clean Air Act is 42 (USEPA 1997).[28]

It may be useful to highlight differences in how the Clean Air and Clean Water Acts answer four important questions about environmental regulation. These comparisons also highlight features of the Clean Water Act which are not widely recognized and could lead it to have lower net benefits than some other environmental regulation.

First is the choice of policy instrument. Market-based instruments are believed to be more cost-effective than alternatives. Parts of the Clean Air Act use cap-and-trade systems, but nearly none of the Clean Water Act does. The grants we study actually subsidize the adoption of pollution control equipment, which is a common policy globally that has undergone little empirical economic analysis.

A second question is scope. Cost-effective regulation equates marginal abatement costs across sources, which requires regulating all sources. The Clean Air Act covers essentially all major polluting sectors. The Clean Water Act, by contrast, mostly ignores "non-point" pollution sources like agriculture. Ignoring such a large source of pollution can make aggregate abatement more costly.

A third question involves substitution. Optimizing consumers should equate the marginal disutility of pollution to the marginal cost of protection from pollution. People breathe the air quality where they live, and relocating to another airshed or some other defenses against air pollution are costly (Deschenes, Greenstone and Shapiro 2017). For water pollution, however, people can more easily substitute between nearby clean and dirty rivers for recreation.

A fourth question involves health. Air is typically unfiltered when it is inhaled, so air pollution is believed to have large mortality consequences that account for much of the benefits of air pollution regulation. Surface waters, by contrast, are typically filtered through a drinking water treatment plant before people drink them. Most analyses of recent U.S. water quality regulation count little direct benefit from improving human health (Lyon and Farrow 1995; Freeman III 2000; USEPA 2000a; Olmstead

[28] Analyses of the Clean Air Act relying solely on hedonic estimates generally have smaller cost-benefit ratios; the EPA's benefit numbers for air pollution rely heavily on estimated mortality impacts.

2010).[29]

Finally, we note one similarity between and air water pollution that may be relevant to policy design. We find some evidence that the net benefits of Clean Water Act grants vary over space in tandem with population density and the popularity of water-based recreation. Related patterns have been found for air pollution, and suggest that allowing the stringency of pollution regulation to vary over space has potential to increase social welfare.

Iowa State and CARD

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References

Adler, Robert W., Jessica C. Landman, Diane M. Cameron, *The Clean Water Act 20 Years Later*, (Washington, D.C.: Island Press, 1993).

Aidt, Toke S., "Political Internalization of Economic Externalities and Environmental Policy," *Journal of Public Economics* , 69 (1998), 1–16.

Albouy, David, "What are Cities Worth? Land Rents, Local Productivity, and the Total Value of Amenities," *Review of Economics and Statistics* , 98 (2016), 477–487.

Alsan, Marcella, Claudia Goldin, "Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880 to 1920," *Journal of Political Economy* ,(Forthcoming).

American Society of Civil Engineers, "Failure to Act: The Economic Impact of Current Investment Trends in Water and Wastewater Treatment Infrastructure," Technical report, ASCE, 2011.

Angrist, Joshua D., Jorn-Steffen Pischke, *Mostly Harmless Econometrics: An Empiricist's Companion*, (Princeton, NJ: Princeton University Press, 2009).

Artell, Janne, Heini Ahtiainen, Eija Pouta, "Subjective vs. Objective Measures in the Valuation of Water Quality," *Journal of Environmental Economics and Management* , 130 (2013), 288–296.

Banzhaf, H. Spencer, "Panel Data Hedonics: Rosen's First Stage and Difference-in-Differences as "Sufficient Statistics"," 2015, Mimeo, Georgia State.

Becker, Randy A., "Water Use and Conservation in Manufacturing: Evidence from U.S. Microdata," *Water Resources Management* , 30 (2016), 4185–4200.

Boscoe, Francis P., Kevin A. Henry, Michael S. Zdeb, "A Nationwide Comparison of Driving Distance Versus Straight-Line Distance to Hospitals," *Professional Geographer* , 64 (2012), 188–96.

[29]This contrasts with the regulation of surface water quality in developing countries and in the historic U.S. (Ebenstein 2012; Alsan and Goldin Forthcoming), where drinking water is less well filtered, piped water access less widespread, and stringent drinking water standards less common or less well enforced.

Carson, Richard T., Robert Cameron Mitchell, "The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water," *Water Resources Research* , 29 (1993), 2445–2454.

CBO, "Efficient Investment in Wastewater Treatment Plants," Technical report, Congressional Budget Office, 1985.

Cohen, Alex, David A. Keiser, "The Effectiveness of Incomplete and Overlapping Pollution Regulation: Evidence From Bans on Phosphate in Automatic Dishwasher Detergent," *Journal of Public Economics* , 150 (2017), 53–74.

Cropper, Maureen, Wallace E. Oates, "Environmental Economics: A Survey," *Journal of Economic Literature* , 30 (1992), 675–740.

Currie, Janet, Joshua Graff Zivin, Katherine Meckel, Matthew Neidell, Wolfram Schlenker, "Something in the Water: Contaminated Drinking Water and Infant Health," *Canadian Journal of Economics* , 46 (2013), 791–810.

Deschenes, Olivier, Michael Greenstone, Joseph S. Shapiro, "Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program," *American Economic Review* , 107 (2017), 2958–2989.

Earnhart, Dietrich, "Panel Data Analysis of Regulatory Factors Shaping Environmental Performance," *Review of Economics and Statistics* , 86(1) (2004a), 391–401.

———, "Regulatory Factors Shaping Environmental Performance at Public-Owned Treatment Plants," *Journal of Environmental Economics and Management* , 48 (2004b), 655–681.

Ebenstein, Avraham, "The Consequences of Industrialization: Evidence from Water Pollution and Digestive Cancers in China," *Review of Economics and Statistics* , 94 (2012), 186–201.

Faulkner, H., A. Green, K. Pellaumail, T. Weaver, "Residents' Perceptions of Water Quality Improvements Following Remediation Work in the Pymme's Brook Catchment, North London, UK," *Journal of Environmental Management* , 62 (2001), 239–254.

Fowlie, Meredith, Nicholas Muller, "Market-Based Emissions Regulation When Damages Vary Across Sources: What are the Gains from Differentiation?," *Journal of the Association of Environmental and Resource Economists* ,(Forthcoming).

Fredriksson, Per G., "Environmental Policy Choice: Pollution Abatement Subsidies," *Resource and Energy Economics* , 20 (1998), 51–63.

Freeman III, A. Myrick, "Water Pollution Policy," in *Public Policies for Environmental Protection*, Portney, Paul R., ed., (Washington, D.C.: Resources for the Future, 2000), 169-213.

Gamkhar, Shama, Anwar Shah, "The Impact of Intergovernmental Fiscal Transfers: A Synthesis of the Conceptual and Empirical Literature," in *Intergovernmental Fiscal Transfers: Principles and Practice*, Boadway, Robin, and Anwar Shah, eds., (Washington, D.C.: World Bank, 2007), 225-258.

Gianessi, Leonard P., Henry M. Peskin, "Analysis of National Water Pollution Control Policies: 2. Agricultural Sediment Control," *Water Resources Research* , 17(4) (1981), 803–821.

Glaeser, Edward L., Joseph Gyourko, "Urban Decline and Durable Housing," *Journal of Political Economy* , 113 (2005), 345–375.

Greenstone, Michael, Rema Hanna, "Environmental Regulations, Air and Water Pollution, and Infant Mortality in India," *American Economic Review* , 104 (2014), 3038–72.

Harrington, Winston, "Industrial Water Pollution in the United States: Direct Regulation or Market Incentive?," in *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe* , Harrington, Winston, Richard D. Morgenstern, and Thomas Sterner, eds., (Washington, D.C.: Resources for the Future, 2004), 67-90.

Hausman, Jerry, "Contingent Valuation: From Dubious to Hopeless," *Journal of Economic Perspectives* , 26 (2012), 43–56.

Hines, James R., Richard H. Thaler, "The Flypaper Effect," *Journal of Economic Perspectives* , 9 (1995), 217–226.

Hines, N. William, "Nor Any Drop to Drink: Public Regulation of Water Quality. Part I: State Pollution Control Programs," *Iowa Law Review* , 186 (1967).

Jeon, Yongsik, Joseph A. Herriges, Catherine L. Kling, John Downing, "The Role of Water Quality Perceptions in Modelling Lake Recreation Demand," in *The International Handbook on Non-Market Environmental Valuation*, Bennett, Jeff, ed., (Northampton, MA: Edward Elgar, 2011), 74-101.

Jondrow, James, Robert A. Levy, "The Displacement of Local Spending for Pollution Control by Federal Construction Grants," *American Economic Review Papers and Proceedings* , 74 (1984), 174–8.

Kahn, Matthew E., Pei Li, Kaxuan Zhao, "Water Pollution Progress at Borders: The Role of Changes in China's Political Propotion Incentives," *American Economic Journal: Economic Policy* , 7 (2015), 223–242.

Keiser, David A., "The Missing Benefits of Clean Water and the Role of Mismeasured Pollution Data," *Journal of the Association of Environmental and Resource Economists* ,(Forthcoming).

Kline, Patrick, Christopher Walters, "Evaluating Public Programs with Close Substitutes: The Case of Head Start," *Quarterly Journal of Economics* , 131 (2016), 1795–1848.

Kling, Catherine L., Daniel J. Phaneuf, Jinhua Zhao, "From Exxon to BP: Has Some Number Become Better than No Number," *Journal of Economic Perspectives* , 26 (2012), 3–26.

Knopman, Debra S., Richard A. Smith, "Twenty Years of the Clean Water Act: Has U.S. Water Quality Improved?," *Environment* , 35 (1993), 17–41.

Kohn, Robert E., "When Subsidies for Pollution Abatement Increase Total Emissions," *Southern Economic Journal* , 59 (1992), 77–87.

Kuwayama, Yusuke, Sheila Olmstead, "Water Quality and Economics: Willingness to Pay, Efficiency, Cost-effectiveness, and New Research Frontiers," in *Handbook on the Economics of Natural Resources* , Layton, David, and Robert Halvorsen, eds., (Northampton, MA: Edgar Elgar, 2015), 474-501.

Leggett, Christopher G., Nancy E. Bockstael, "Evidence of the Effects of Water Quality on Residential Land Prices," *Journal of Environmental Economics and Management* , 39 (2000), 121–144.

Lipscomb, Molly, Ahmed Mushfiq Mobarak, "Decentralization and Pollution Spillovers: Evidence from the Re-drawing of Country Borders in Brazil," *Review of Economic Studies* , 84 (2017), 464–502.

Lutz, Byron, "Taxation with Representation: Intergovernmental Grants in a Plebiscite Democracy," *Review of Economics and Statistics* , 92 (2010), 316–332.

Lyon, Randolph M., Scott Farrow, "An Economic Analysis of Clean Water Act Issues," *Water Resources Research* , 31 (1995), 213–223.

McFadden, Daniel, Kenneth Train, *Contingent Valuation of Environmental Goods*, (Northampton, MA: Edward Elgar, 2017).

Mehan III, G. Tracy, "A Symphonic Approach to Water Management: The Quest for New Models of Watersed Governance," *Journal of Land Use & Environmental Law* , 26 (2010), 1–33.

Millock, Katrin, Celine Nauges, "Ex Post Evaluation of an Earmarked Tax on Air Pollution," *Land Economics* , 82 (2006), 68–84.

Moeltner, Klaus, Roger von Haefen, "Microeconometric Strategies for Dealing with Unobservables and Endogenous Variables in Recreation Demand Models," *Annual Reviews of Resource Economics* , 3 (2011), 375–96.

Muehlenbachs, Lucija, Elisheba Spiller, Christopher Timmins, "The Housing Market Impacts of Shale Gas Development," *American Economic Review* , 105 (2015), 3633–59.

Muller, Nicholas Z., Robert Mendelsohn, "Efficient Pollution Regulation: Getting the Prices Right," *American Economic Review* , 99 (2009), 1714–1739.

Muller, Nicholas Z., Robert Mendelsohn, William Nordhaus, "Environmental Accounting for Pollution in the United States Economy," *American Economic Review* , 101 (2011), 1649–1675.

Murdock, Jennifer, "Handling unobserved site characteristics in random utility models of recreational demand," *Journal of Environmental Economics and Management* , 51 (2006), 1–25.

Nixon, Richard, "Presidential Veto Message: Nixon Vetoes Water Pollution Act," *CQ Almanac* .

Oates, Wallace E., "An Essay on Fiscal Federalism," *Journal of Economic Literature* , 37 (1999), 1120–1149.

Olmstead, Sheila M., "The Economics of Water Quality," *Review of Environmental Economics & Policy* , 4 (2010), 44–61.

Olmstead, Sheila M., Lucija A. Muehlenbachs, Jhih-Shyang Shih, Ziyan Chu, Alan J. Krupnick, "Shale gas development impacts on surface water quality in Pennsylvania," *Proceedings of the National Academy of Sciences* , 110 (2013), 4962–4967.

Peiser, Richard B., Lawrence B. Smith, "Homeownership Returns, Tenure Choice and Inflation," *Real Estate Economics* , 13 (1985), 343–360.

Poor, P. Joan, Kevin J. Boyle, Laura O. Taylor, Roy Bouchard, "Objective versus Subjective Measures of Water Clarity in Hedonic Property Value Models," *Land Economics* , 77 (2001), 482–493.

Powell, Mary, "Building a National Water Quality Monitoring Program," *Environmental Science & Technology* , 29 (1995), 458A–463A.

Roback, Jennifer, "Wages, Rents, and the Quality of Life," *Journal of Political Economy* , 90 (1982), 1257–1278.

Shapiro, Joseph S., Reed Walker, "Why is Pollution from U.S. Manufacturing Declining? The Roles of Environmental Regulation, Productivity, and Trade," *American Economic Review* ,(Forthcoming).

Sigman, Hilary, "International Spillovers and Water Quality in Rivers: Do Countries Free Ride?," *American Economic Review* , 92 (2002), 1152–1159.

———, "Letting States Do the Dirty Work: State Responsibility for Federal Environmental Regulation," *National Tax Journal* , 56 (2003), 107–122.

———, "Transboundary Spillovers and Decentralization of Environmental Policies," *Journal of Environmental Economics and Management* , 50 (2005), 82–101.

Smith, Richard A., Richard B. Alexander, M. Gordon Wolman, "Water-Quality Trends in the Nation's Rivers," *Science* , 235 (1987), 1607–1615.

Smith, V. Kerry, William H. Desvousges, *Measuring Water Quality Benefits*, (Boston, MA: Kluwer, 1986).

Smith, V. Kerry, Carlos Valcarcel Wolloh, "Has Surface Water Quality Improved Since the Clean Water Act?," NBER Working Paper 18192, 2012.

Steinwender, Astrid, Caludia Gundacker, Karl J. Wittmann, "Objective Versus Subjective Assessments of Environmental Quality of Standing and Running Waters in a Large City," *Landscape and Urban Planning* , 84 (2008), 116–126.

Stigler, George J., *The Theory of Price*, (New York, NY: Macmillan, 1952).

Stigler, George Joseph, *The Theory of Price*, (New York, NY: Macmillan, 1966).

Time, "The Cities: The Price of Optimism," *Time Magazine* , August 1 (1969).

U.S. Census Bureau, "1967 Census of Manufactures: Water Use in Manufacturing," Technical report, U.S. Census Bureau, 1971.

USDOT, 2009 National Household Travel Survey, Federal Highway Administration, 2009.

USEPA, "National Water Quality Inventory. 1974 Report to the Congress. Volume II," Technical report, USEPA, 1974.

———, "Clean Water Construction Grants Program News," Technical report, USEPA, 1975.

———, "Handbook of Procedures: Construction Grants Program for Municipal Wastewater Treatment Works," Technical report, USEPA, 1980, Second Edition.

———, "The Benefits and Costs of the Clean Air Act, 1970 to 1990," Technical report, USEPA, 1997.

———, "A Benefits Assessment of Water Pollution Control Programs Since 1972: Part 1, The Benefits of Point Source Controls for Conventional Pollutants in Rivers and Streams: Final Report," Technical report, USEPA, 2000a.

———, "Liquid Assets 2000: America's Water Resources at a Turning Point," Technical report, Office of Water, 2000b.

———, "A Retrospective Assessment of the Costs of the Clean Water Act: 1972 to 1997: Final Report," Technical report, USEPA, 2000c.

———, "Progress in Water Quality: An Evaluation of the National Investment in Municipal Wastewater Treatment," Technical report, Office of Water, 2000b.

———, "The National Costs to Implement TMDLs (Draft Report): Support Document 2," Technical report, USEPA, 2001.

———, "The Clean Water and Drinking Water Infrastructure Gap Analysis," Technical report, USEPA, 2002.

———, "30 Years of the NADP," Technical report, USEPA, 2007.

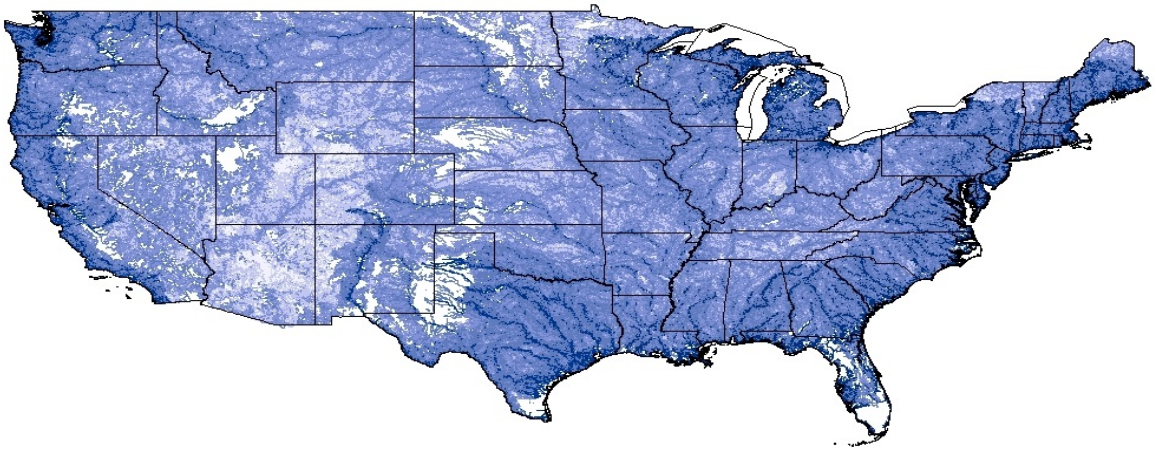
———, "ATTAINS, National Summary of State Information," 2016, Accessed June 15, 2016.

USGAO, "Water Pollution: Information on the Use of Alternative Wastewater Treatment Systems," Technical report, USGAO, 1994.

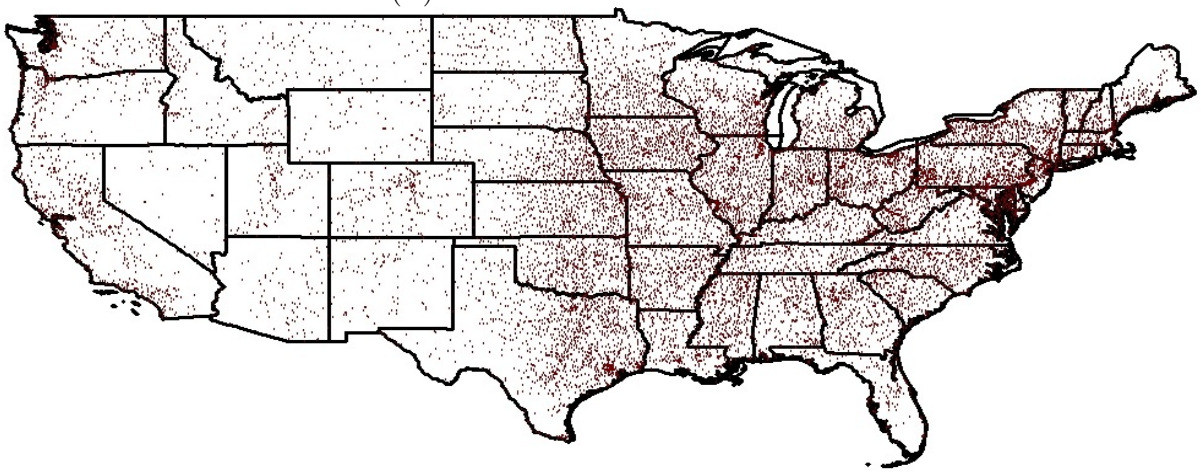
Wu, Junjie, Richard M. Adams, Catherine L. Kling, Katsuya Tanaka, "From Microlevel Decisions to Landscape Changes: An Assessment of Agricultural Conservation Policies," *American Journal of Agricultural Economics* , 86 (2004), 26–41.

FIGURE I
National Maps of Water Pollution Data

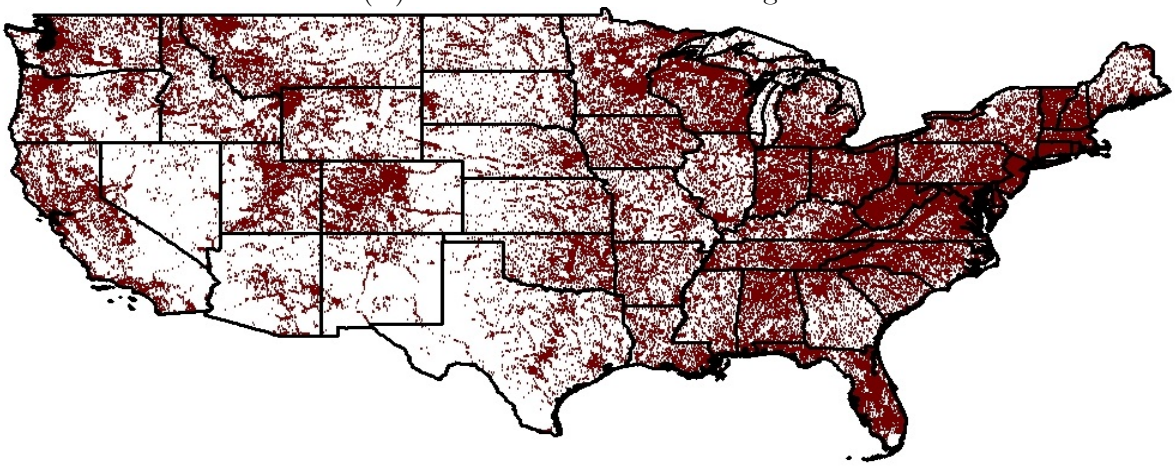
(A) The River and Stream Network



(B) Wastewater Treatment Plants



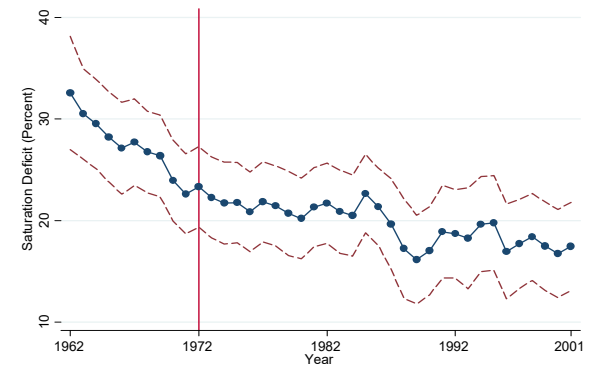
(C) Water Pollution Monitoring Sites



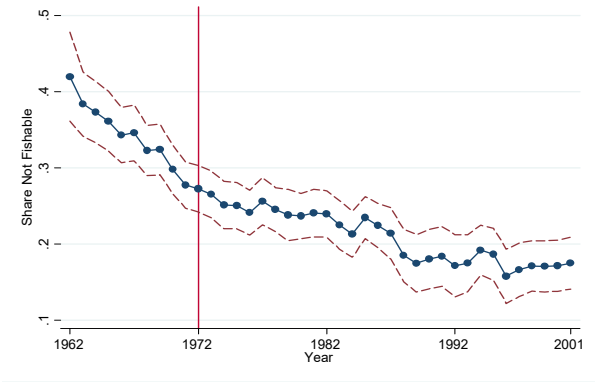
Notes: In Panel A, rivers are colored by Stream Level from the National Hydrography Dataset. Streams that flow into oceans, Great Lakes, Canada or Mexico and are the darkest. Streams that flow into these are lighter; streams that flow into these are still lighter, etc. Panel B includes wastewater treatment plants used in analysis (continental U.S., within 1km of a river, etc.). Panel C shows monitoring sites appearing in years 1962-2001.

FIGURE II
Water Pollution Trends, 1962-2001

(A) Dissolved Oxygen Deficit



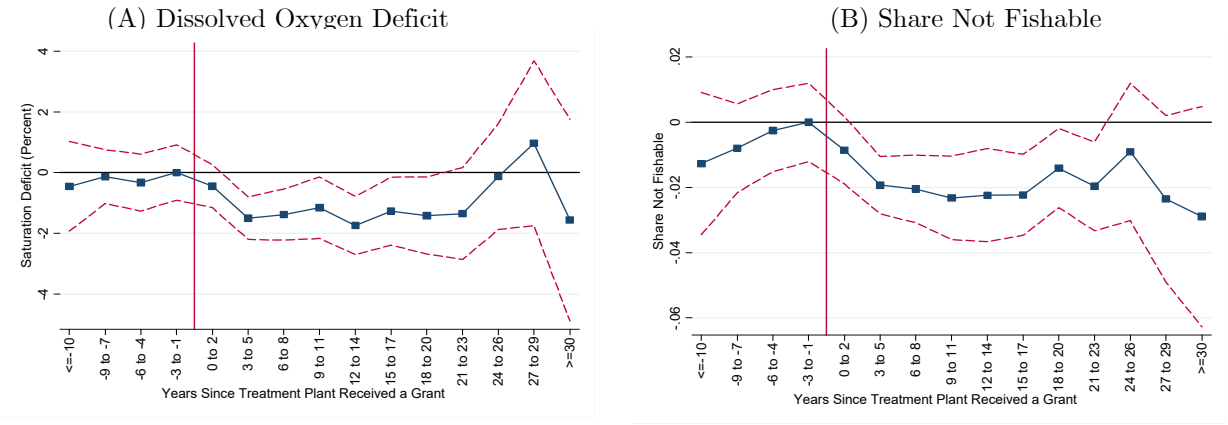
(B) Share Not Fishable



Notes: Graphs show year fixed effects plus a constant from regressions which also control for monitoring site fixed effects, a day-of-year cubic polynomial, and an hour-of-day cubic polynomial, corresponding to equation (1) from the text. Connected dots show yearly values, dashed lines show 95% confidence interval, and 1962 is reference category. Standard errors are clustered by watershed.

FIGURE III

Effects of Clean Water Act Grants on Water Pollution: Event Study Graphs

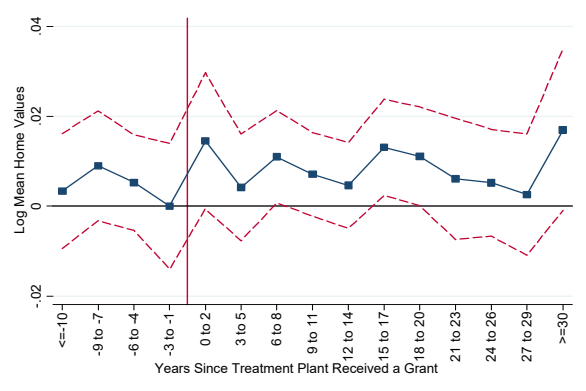


Notes: Graphs show coefficients on downstream times year-since-grant indicators from regressions which correspond to the specification of Table II. These regressions are described in equation (4) from the main text. Data cover years 1962-2001. Connected dots show yearly values, dashed lines show 95% confidence interval. Standard errors are clustered by watershed.

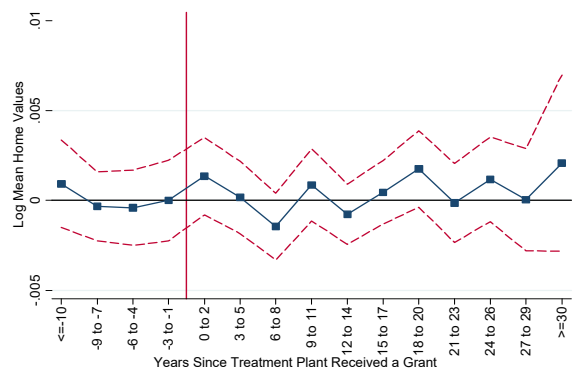
FIGURE IV

Effects of Clean Water Act Grants on Log Mean Home Values: Event Study Graphs

(A) Homes Within 0.25 Miles of River



(B) Homes Within 25 Miles of River



Notes: Graphs show coefficients on year-since-grant indicators from regressions corresponding to the specification of Table V, columns (2) and (4). Connected dots show yearly values, dashed lines show 95% confidence interval. Standard errors are clustered by watershed. Panels A and B show different ranges of values on their y-axes. Data cover decennial census years 1970-2000.

TABLE I
WATER POLLUTION TRENDS, 1962-2001

	Main Pollution Measures		Other Pollution Measures			
	Dissolved Oxygen Deficit	Not Fishable	Biochemical Oxygen Demand	Fecal Coliforms	Not Swimmable	Total Suspended Solids
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Linear Trend						
Year	-0.240***	-0.005***	-0.065***	-81.097***	-0.005***	-0.915***
	(0.0296)	(0.0003)	(0.0050)	(8.3260)	(0.0003)	(0.0921)
Panel B. 1972 Trend Break						
Year	-1.027***	-0.015***	-0.124***	-255.462***	-0.018***	-1.113*
	(0.147)	(0.002)	(0.020)	(82.529)	(0.002)	(0.574)
Year *	0.834***	0.011***	0.062***	179.134**	0.014***	0.203
1[Year>=1972]	(0.157)	(0.002)	(0.021)	(81.457)	(0.002)	(0.596)
1972 to 2001 change	-5.583	-0.118	-1.794	-2,213.510	-0.114	-26.363
	(0.902)	(0.009)	(0.148)	(236.581)	(0.010)	(2.777)
N	5,852,148	10,969,154	1,273,390	2,070,351	10,969,154	1,720,749
Dep. Var. Mean	17.78	0.25	3.98	2,958.11	0.50	49.75
Monitor Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Season Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time of Day Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each observation in the data is a pollution reading. Data includes years 1962-2001. Dissolved oxygen deficit equals 100 minus dissolved oxygen saturation, measured in percentage points. Season controls are a cubic polynomial in day of year. Time of Day controls are a cubic polynomial in hour of day. In Panel B, the year variables are recentered around the year 1972. The 1972 to 2001 change equals the fitted value Year*29 + Year*1[Year≥1972]*29. Dependent variable mean refers to years 1962-1971. Standard errors are clustered by watershed. Asterisks denote p-value < 0.10 (*), < 0.05 (**), or < 0.01 (***).

TABLE II
EFFECTS OF CLEAN WATER ACT GRANTS ON WATER POLLUTION

	Main Pollution Measures		Other Pollution Measures			
	Dissolved Oxygen Deficit	Not Fishable	Biochemical Oxygen Demand	Fecal Coliforms	Not Swimmable	Total Suspended Solids
	(1)	(2)	(3)	(4)	(5)	(6)
Downstream	-0.681***	-0.007**	-0.104**	-204.059**	-0.004*	-0.497
* Cumul. # Grants	(0.206)	(0.003)	(0.041)	(98.508)	(0.002)	(0.635)
N	55,950	60,400	28,932	34,550	60,400	30,604
Dep. Var. Mean	17.092	0.328	4.411	5731.028	0.594	42.071
Fixed Effects:						
Plant-Downstream	Yes	Yes	Yes	Yes	Yes	Yes
Plant-Year	Yes	Yes	Yes	Yes	Yes	Yes
Downst.-Basin-Year	Yes	Yes	Yes	Yes	Yes	Yes
Weather	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each observation in a regression is a plant-downstream-year tuple. Data cover years 1962-2001. Dissolved oxygen deficit equals 100 minus dissolved oxygen saturation, measured in percentage points. Dependent Variable Mean describes mean in years 1962-1972. Standard errors are clustered by watershed. Asterisks denote p-value $<$ 0.10 (*), $<$ 0.05 (**), or $<$ 0.01 (***).

TABLE III

COST EFFECTIVENESS OF CLEAN WATER ACT GRANTS ($2014 MN)

	(1)	(2)	(3)
1. Total Costs	296,757	396,802	549,890
2. Federal Capital Costs	87,926	117,691	164,413
3. Local Capital Costs	37,296	49,958	68,309
4. Operation & Maintenance Costs	171,536	229,153	317,168
5. River-Miles Made Fishable	5,188	9,000	12,260
6. River Miles * Pct. Saturation Increase / 10	14,721	25,536	34,787
7. Annual Cost to Make a River-Mile Fishable	1.91	1.47	1.50
	[1.35 , 3.22]	[1.04 , 2.48]	[1.06 , 2.53]
8. Annual Cost to Increase Dissolved Oxygen	0.67	0.52	0.53
Saturation in a River-Mile by 10%	[0.42 , 1.65]	[0.33 , 1.27]	[0.33 , 1.29]
Plants with Water Quality Data	Yes		
Georeferenced Plants		Yes	
Assume 25 Miles Downstream			Yes

Notes: Dollar values in $2014 millions. Brackets show 95% confidence intervals. Rows 2-3 are aggregated from GICS microdata. Row 4 is calculated following the method described in Appendix B.4. Row 5 is calculated by multiplying each grant by the parameter estimate in Appendix Table VI, Row 13, Column 2, and applying the result to all waters within 25 miles downstream of the treatment plant. Row 6 is calcualted by multiplying each grant by the parameter estimate in Table II, Column 1, and applying the result to all waters within 25 miles downstream of the treatment plant. Row 7 equals row 1 divided by thirty times row 5, since it assumes water quality improvements accrue for 30 years. Row 8 equals row 1 divided by thirty times row 6. Column 1 includes only plants analyzed in Column 2 of Table II. Column 2 includes plants in continental U.S. with latitude and longitude data. Column 3 includes all plants and grants with minimum required data (e.g., grants linked to the exact treatment plant even if without latitude or longitude data) and assumes all plants have 25 miles of rivers downstream.

TABLE IV
PASS-THROUGH OF GRANTS TO MUNICIPAL SEWERAGE CAPITAL SPENDING

	(1)	(2)	(3)	(4)
Panel A. Federal Grant Funds				
Federal Grant Funds	1.52***	1.26***	1.13***	1.19***
	(0.29)	(0.22)	(0.27)	(0.31)
Panel B. Grant Project Costs				
Grant Project Costs	1.09***	0.93***	0.84***	0.89***
	(0.21)	(0.16)	(0.19)	(0.23)
City FE and Year FE	Yes	Yes	Yes	Yes
Real Costs		Yes	Yes	Yes
Basin-by-Year FE			Yes	Yes
Propensity Score Reweight				Yes

Notes: Dependent variable is municipal sewerage capital investment. Municipal and grant costs are cumulative since 1970. Grant project costs include federal grant amount and required local capital expenditure. Municipal spending data from Annual Survey of Governments and Census of Governments. Data include balanced panel of cities over years 1970-2001, see text for details. Propensity score for appearing in the balanced panel of cities is estimated as a function of log city population, log city total municipal expenditure, city type (municipality or township), and census division fixed effects, where city population and expenditure are averaged over all years of the data. Standard errors are clustered by city. Sample size in all regressions is 6,336. Asterisks denote p-value < 0.10 (*), <0.05 (**), or 0.01 (***).

TABLE V
EFFECTS OF CLEAN WATER ACT GRANTS ON HOUSING DEMAND

	(1)	(2)	(3)	(4)
Panel A. Log Mean Home Values				
Cumulative Grants	-0.00022	0.00076	0.002486*	0.00024
	(0.002507)	(0.001409)	(0.001271)	(0.000328)
Panel B. Log Mean Rental Values				
Cumulative Grants	0.00005	-0.00078	0.00007	-0.00012
	(0.001682)	(0.000832)	(0.000714)	(0.000158)
Panel C. Log Total Housing Units				
Cumulative Grants	-0.006965**	-0.00031	-0.00031	-0.00016
	(0.003180)	(0.001176)	(0.000939)	(0.000241)
Panel D. Log Total Value of Housing Stock				
Cumulative Grants	-0.006356*	0.00010	0.00144	-0.00015
	(0.003275)	(0.001878)	(0.001592)	(0.000461)
Plant FE, Basin-by-Year FE	Yes	Yes	Yes	Yes
Dwelling Characteristics		Yes	Yes	Yes
Baseline Covariates * Year		Yes	Yes	Yes
Max Distance Homes to River (Miles)	0.25	0.25	1	25

Notes: Analysis includes homes within a given distance of downstream river segments. Data include decennial census years 1970-2000. Cumulative grants include grants in all previous years, not only census years. See main text for description of dwelling and baseline covariates. Home prices and rents are deflated to year 2014 dollars by the Bureau of Labor Statistics consumer price index for urban consumers. Standard errors are clustered by watershed. Asterisks denote p-value < 0.10 (*), < 0.05 (**), or < 0.01 (***).

TABLE VI

CLEAN WATER ACT GRANTS: COSTS AND EFFECTS ON HOME VALUES ($2014BN)

	(1)	(2)	(3)	(4)
Ratio: Change in Home	0.06	0.26	0.22	0.24
Values / Costs	(0.03)	(0.36)	(0.36)	(0.41)
p-value: Ratio = 0	[0.05]	[0.46]	[0.55]	[0.56]
p-Value: Ratio = 1	[0.00]	[0.04]	[0.03]	[0.06]
Change in Value of Housing ($Bn)	15.92	89.25	73.7	91.97
Costs ($Bn)				
Capital: Fed.	86.24	102.26	102.26	114.16
Capital: Local	35.81	41.81	41.81	48.00
Variable	166.1	197.36	197.36	222.81
Total	288.15	341.44	341.44	384.97
Max Distance Homes to River (Miles)	1	25	25	25
Include Rental Units			Yes	Yes
Include Non-Metro Areas				Yes

Notes: All values in billions ($2014). Calculations include grants given in years 1962-2000. Ninety-five percent confidence regions are in brackets. Estimates come from regression specifications corresponding to Table V, columns (3) and (4).