Costs, Benefits, and Incidence of Environmental Policy in the Twenty First Century[1]

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Abstract

This paper discusses four hypotheses about US pollution over the last half century. First, air and water pollution have declined substantially, though greenhouse gas emissions have not. Second, environmental policy explains a large share of these trends. Third, much regulation of air and drinking water pollution has benefits above costs, though evidence for surface water quality regulation is less clear. Fourth, while the distribution of pollution across social groups is unequal, market-based environmental policies do not systematically improve or worsen the inequality of environmental outcomes relative to command-and-control standards. I also discuss recent innovations in methods and data used to evaluate these hypotheses, including increasing use of environmental administrative data, statistical cost-benefit comparisons, analysis of previously understudied policies, more detailed approaches to pollution transport, micro-macro frameworks, and a focus on the distribution of environmental outcomes. One goal of describing these hypotheses is to frame a common research agenda advancing in environmental economics.

[1] I gave a version of this paper as the keynote address at the summer 2021 conference of the Association of Environmental and Resource Economists. I thank participants in that session for useful questions and comments. I gratefully acknowledge discussions with Mark Jacobsen, Dave Keiser, Cathy Kling, Jim Sallee, Arthur van Benthem, and Reed Walker which informed my thinking in this paper and research it discusses, and Lucy Hackett and Calvin Tolbert for excellent research assistance.

In the 1960s, concern about the US environment grew rapidly. Many causes contributed, including Rachel Carson's *Silent Spring*, pictures of Earth taken from space, an oil spill off Santa Barbara, the discovery of probable carcinogens in urban drinking water, the first Earth Day in 1970, and a fire on the Cuyahoga River in Cleveland, Ohio. Underlying these causes was a fear that amidst the prosperous postwar period, environmental degradation driven by industrialization threatened to undermine US quality of life. Reflecting prevailing fears of the time, the controversial *Limits to Growth* report (Meadows et al. 1972) described a future where pollution would grow exponentially for a century.

These events contributed to enormous support for environmental policy. The federal government in the early 1970s created the Environmental Protection Agency and passed the Clean Air Act, Clean Water Act, Safe Drinking Water Act, and many other influential environmental policies. These laws had substantial bipartisan support. For example, the Senate passed the 1970 Clean Air Act Amendments without a single nay vote, and the House approved the 1972 Clean Water Act with a vote of 247-23.

A half century has passed since these laws, and the growth of both economic research and political debates on these laws give reason to step back. This paper proposes four hypotheses describing what we have learned:

- **Hypothesis 1 (trends)**: Air pollution, drinking water pollution, and surface water pollution have declined substantially over previous decades, though CO_2 emissions have not.
- **Hypothesis 2 (causes)**: Environmental policy explains a large share of these trends.
- **Hypothesis 3 (consequences)**: Much regulation of air and drinking water policies has benefits above costs; evidence for surface water is less clear.
- **Hypothesis 4 (environmental incidence)**: Market-based policies and command-and-control policies do not produce systematically different distributions of environmental outcomes.

These are hypotheses, not theses. I discuss evidence for each. For Hypothesis 1, evidence for air, surface water, and CO_2 trends is strong, while evidence for drinking water trends is less clear. For Hypothesis 2, I discuss suggestive evidence from specific settings, though comprehensive evidence is not available. For Hypothesis 3, I focus on evidence around air pollution, though I also discuss the more limited evidence on surface water pollution. For Hypothesis 4, research is emerging; this hypothesis represents a conjecture summarizing the few available studies.

While I highlight what is known about specific aspects of these hypotheses, much about them is unknown. My goal in organizing the paper around these hypotheses is both to highlight open questions of importance and to explain methods and findings from individual papers.

Some relationships among these hypotheses are worth noting. The first two hypotheses provide a coherent narrative. Air, surface water, and drinking water pollution produce immediate negative and local externalities which give local residents an incentive to pressure policymakers to control them. In part for this reason, stringent environmental policies have targeted these pollutants. But CO_2 emissions produce gradual global negative externalities which give local residents a weaker incentive to address them. In part for these reasons, CO_2 policy has been weaker, which helps explain why CO_2 has not experienced similar declines as air and water pollution.

The first and third hypotheses also provide an informative comparison. The first hypothesis describes large changes in pollution over time. Researchers typically assume that the marginal cost of cleaning up pollution increases with the quantity of cleanup, i.e., marginal abatement costs increase with abatement. Given the large decreases in pollution the first hypothesis describes, one might wonder at what point the marginal cost of cleaning up pollution rises enough to equal its benefits. This third hypothesis suggests that despite large and increasing pollution control, benefits of some marginal environmental improvements continue to exceed their costs for air pollution, though the situation for surface water pollution is less clear.

The third and fourth hypotheses also provide a natural comparison to fundamental results in welfare economics. The First Welfare Theorem states that under certain assumptions, including the absence of externalities, a competitive equilibrium is Pareto Efficient. The Second Welfare Theorem states that any Pareto Efficient allocation can be achieved as a competitive equilibrium given certain endowments. The third hypothesis represents a natural corollary of the First Welfare Theorem—in the presence of externalities, a competitive equilibrium in the absence of policy is not optimal, but policies that internalize the externalities can increase social welfare. The fourth hypothesis relates more to the Second Welfare Theorem—changing the distribution of economic goods like the environment can produce different allocations of goods without affecting efficiency. Put another way, one can still use efficient policy tools like pollution pricing to achieve a range of distributional outcomes.

One clarification of the fourth hypothesis is important. The distribution of environmental outcomes refers to the levels of pollution that different individuals experience. It provides an incomplete measure of distribution and incidence. A more complete measure would account for how different policy instruments affect the returns to capital and labor for different individuals, heterogeneous price indices for goods that different individuals consume, and potentially interactions with other taxes (Bovenberg and Goulder 1996). While the fourth hypothesis does not fully characterize social welfare, it does describe an important component of incidence that is an increasing focus of research policy.

I also highlight advances in several areas that have improved the ability of research to test these hypotheses:

- **Administrative data on environmental goods.** Administrative data are collected in order to administer a policy, but scholars are increasingly able to use these detailed data for research.
- **Statistical cost-benefit tests**. Historically, many studies would estimate one set of elasticities and then rely heavily on external estimates from other policies, locations, or populations (sometimes called "benefits transfer"). In some more recent settings, research can compare total or marginal costs and benefits from a single setting, without relying on external estimates from other settings. Additionally, some studies estimate confidence regions for differences between benefits and costs.
- **Focus on important but understudied policies**. Some policies have played central roles in US environmental policy over the last half century but until recently have not been a focus of research.
- **Richer models of pollution transport**. Increasing scientific understanding of how pollution emissions in one location affect pollution concentrations in other locations and increasing use of chemical dispersion and hydrological routing models allow economic research to examine where pollution is emitted, where it affects air and water quality, and how these two relate.
- **Micro-macro frameworks**. Some research combines detailed microdata on individual firms and households, transparent identification of key elasticities, microfounded models of firm and consumer optimization behavior, and aggregation over an entire sector or economy. These types of micro-macro frameworks can seek to examine to what extent specific individual policies account for aggregate macroeconomic changes in the environment.
- **Focus on the distribution of environmental outcomes**. While research has long studied the distributional consequences of economic policy, a recent body of research takes as its main focus the effects of policy on the locations where pollution is emitted and affects environmental quality.

This paper provides a limited review. It focuses disproportionately on research I have been involved in, focuses almost exclusively on the US, and mostly overlooks natural resources like fisheries, forests, biodiversity, groundwater, and others. I abstract from these goods since I have less direct familiarity with them, though also because many leading studies of these goods focus on a single watershed, county, ecosystem, or other individual setting, which can make it harder to generalize.[2] Many of the individual issues and policies discussed here have other articles devoted to them exclusively, which survey the literature.[3] Here instead I describe a general narrative which can be missed by looking in isolation at a single research paper, policy, pollutant, or method.

Hypothesis 1: Air pollution, drinking water pollution, and surface water pollution have declined substantially over previous decades, though CO_2 emissions have not.

This hypothesis describes trends in purely environmental goods. Why is it relevant for economics? Measuring these trends can use insights from hydrology, atmospheric chemistry, environmental engineering, and other fields outside economics. At the same time, measuring environmental goods well is an essential prerequisite to most other tasks economists might undertake—analyzing consumer preferences, firm technologies, policy design, impacts of counterfactuals, etc. Hence, accurate measurement of environmental goods provides a critical input to accurate analysis of them.

Air pollution

Data on the main air pollutants that the Clean Air Act regulates ("criteria" pollutants) are readily available, since the EPA maintains an organized network of monitors. These monitors are operated in part to assess whether counties violate air quality standards – the data are collected partly for administering policy – but are also useful for researching policy.

Ambient concentrations of some air pollutants fell enormously since the 1970s. Between 1980 and 2019, carbon monoxide concentrations fell by 85 percent, ozone by 35 percent, sulfur dioxide by 92 percent, and lead by 98 percent. Between 1990 and 2019, particulate matter (PM_{10}) concentrations fell by 46 percent (USEPA 2021a). Ambient concentrations of CO, SO_2, and particulate matter (TSP) fell by roughly 25 to 35 percent during the 1970s (USEPA 1980; Chay and Greenstone 2005).

Measuring air pollution emissions, as opposed to ambient concentrations, is more complex. A source's emissions depend on numerous variables including energy and materials used, pollution control technology, capital equipment and its maintenance, weather conditions, management quality, and others. Some estimates of emissions come from engineering calibrations, while others come from direct measurement of a plant's smokestack.

While it is important to recognize these caveats for emissions data, reported emissions rates from industrial, transportation, and other sources do show declines of qualitatively similar magnitudes to the declines measured in ambient concentrations. For example, between 1980 and 2019, emissions of CO fell by 75 percent, NO_x fell 58 percent, VOCs fell 59 percent, direct PM_{10} fell 63 percent, and SO_2 fell by 92 percent (USEPA 2021b).

Surface water pollution

Measuring trends in pollution in rivers, lakes, and other surface waters is more challenging. Most surface water quality data are collected by state and local organizations, including a large share from state offices

[2] Increasing access to and quality of remote sensing data is enabling national and global analysis of timber, groundwater, and other natural resources along the lines of some questions discussed in this paper.
[3] Some relevant reviews include Olmstead (2010), Currie and Walker (2019), Hsiang, Oliva, and Walker (2019), Keiser and Shapiro (2019b).

of the US Geological Survey. Groups collect these data for many purposes, including guiding policy. In this respect these are also administrative data, that until a few years ago were largely not accessible for research. The recent creation of the Water Quality Portal (waterqualitydata.us) has enhanced researchers' ability to access and analyze semi-recent water quality data. Older water quality data are available through a retired repository, Storet Legacy.

Common measures of surface water pollution, such as biochemical oxygen demand, dissolved oxygen saturation deficits, fecal coliforms, and total suspended solids have decreased substantially since the 1970s. Between 1972 and 2014, biochemical oxygen demand concentrations fell by about half, dissolved oxygen saturation deficits fell by around 13 percentage points, fecal coliform concentrations fell by about two-thirds, and total suspended solids concentrations fell by about a third (Keiser and Shapiro 2019b).

Not all types of surface water pollution are declining. Many nutrients like nitrogen and phosphorus come from agriculture, which is largely exempt from Clean Water Act regulation. Trends for nutrients are much flatter and for some pollutants increasing (Keiser and Shapiro 2019a).

I do not discuss emissions data for surface water pollution because they are less comparable over time. Large water pollution sources report quarterly emissions to the EPA. Different reporters use different approaches to measurement—reporting concentration versus total quantity, one versus many monitoring sites, different reporting frequency, different pollutants, etc. This makes it more complex to construct representative and comparable trends in surface water pollution emissions.

Drinking water pollution

Measuring trends in drinking water pollution is more difficult. The US has approximately 150,000 drinking water systems. About a third are community water systems serving households; others serve institutions like campgrounds and gas stations. Most community water systems directly or indirectly monitor the roughly 95 contaminants that the Safe Drinking Water Act regulates. But these systems are not required to share these data with federal regulators. Local drinking water systems do report violations of drinking water standards to federal regulators. The EPA has kept records of those violations in a federal database, the Safe Drinking Water Information System.

Many papers measure violations from that federal database, though two issues make it harder to infer trends from those data. First, drinking water standards change and frequently tighten. This makes it unclear whether an increase in violations represents a decrease in absolute water quality or an increase in water quality standards. Second, many drinking water systems have historically failed to report violations to this federal database, making its coverage incomplete, varying over time, and potentially biased.

One study obtains a large balanced sample of drinking water utilities which report violations to this system every year (Allaire, Wu, and Lall 2018). In these data, when the Safe Drinking Water Act tightens standards, the number of violations increases. After those increases, however, the paper finds steady downward trends in violations. These suggest drinking water quality has been improving, though are far from conclusive.

Toxic pollution

Data from the Toxic Release Inventory show sustained and large declines in emissions of many types of toxic pollution to water, air, and land. These data merit more questions about data quality—they fail some data quality tests, it can be unclear how to aggregate totals appropriately across many disparate pollutants, and firms may misreport emissions. In addition, emissions can differ from ambient concentrations, and ambient monitoring of toxic pollutants is limited (Currie et al. 2015). Nonetheless, the available data suggest large and sustained declines in US toxic pollution emissions.

Greenhouse gases

Greenhouse gases are global pollutants—their social cost depends on the quantity of global emissions, not the location where the pollution is emitted. Put another way, the damage from climate change depends only on total tons emitted, not on whether those emissions come from the US or other countries. Nonetheless, it is informative to compare US emissions over time. These data are readily available from EPA emissions inventories.

These data show steady increases in US CO_2 emissions through 2008, and then a gradual decline thereafter. The immediate decline after 2008 is likely due to the Great Recession, though the sustained decline is more likely due to hydraulic fracturing (fracking). One could debate to what extent public subsidies to energy research, policies that increase the cost of coal, and other forces lead to the expansion of fracking in the late 2000s, but regardless, it has decreased US CO_2 emissions. At the same time, the decrease in US CO_2 emissions is far less than the decline in air, surface water, or likely drinking water pollution.

Synopsis

These data support Hypothesis 1—the air and water pollutants with measured concentrations have declined substantially in the past decades, much more than greenhouse gas emissions. At the same time, some caution is warranted. US industry produces or processes thousands of chemicals, many with potential health implications, but the Safe Drinking Water Act only regulates about 95. Because the pollutants that are regulated tend to be the pollutants that are monitored, it is possible that unregulated pollutants have declined less than regulated pollutants. Similarly, this discussion has said little about radioactivity, noise, light, or other externalities which are less a focus of research in environmental economics.

Observing these patterns naturally leads to the question of why air and water pollution have declined more than CO_2. I now turn to the second hypothesis which addresses this question.

Hypothesis 2: Environmental policy provides a leading explanation for these pollution trends.

Why are air and water pollution declining substantially, and why is CO_2 not? This pattern is certainly more beneficial for health than some of the pessimistic predictions of a half century ago, but reasons for these trends are unclear.

One could imagine many explanations besides policy for these trends in pollution. Perhaps these patterns reflect trade and outsourcing—dirty industries and varieties of goods might increasingly be produced in Mexico, China, and other countries with weaker regulation, then imported into the US. Perhaps productivity growth and innovation have let firms produce more output while using fewer polluting inputs like coal. Perhaps "structural transformation," the gradual shift of an economy from agricultural to manufacturing then services, has led to concentration of production in cleaner industries. Perhaps consumer preferences have shifted towards cleaner goods, either due to "warm glow" demand for environmentally friendly products or because people are devoting more expenditure to cleaner goods for reasons not specifically related to the environment.

While many studies look at environmental policies one-at-a-time to assess their consequences, Hypothesis 2 refers more broadly to the aggregate effect of all environmental policies.[4] This kind of hypothesis benefits

[4] Studying many policies at once can allow for analysis of spillovers, complementarities, increasing returns, and other interactions among policies. There are specific examples of this, such as looking at interactions of non-

from a framework that can combine the credible and transparent research designs of applied microeconomic research with the broad approach of many macroeconomic frameworks. I describe two examples of this type of approach. In these two cases, over half and potentially most of the decrease in pollution is due to environmental policy.

Industry

One approach focuses on air pollution emissions from US manufacturing (Shapiro and Walker 2018). Between 1990 and 2008, real output from US manufacturing increased by a third, while air pollution emissions from US manufacturing fell by half or more. What has let firms produce more output while emitting less air pollution? Environmental policy, trade, and innovation provide three potential explanations.

One way to compare the importance of these hypotheses is to analyze a microeconomic model of firm behavior that aggregates to describe economy-wide trends as developed in Shapiro and Walker (2018). This model weaves together features of the Melitz (2003) framework and Copeland and Taylor's (2003) pollution technology.

The basics of the model are as follows. A representative consumer in each country has constant elasticity of substitution utility across varieties of goods, Cobb-Douglas preferences across sectors, and experiences disutility from pollution. On the production side, a measure of entrepreneurs may pay a fixed cost to draw a productivity from a Pareto distribution; once an entrepreneur observes the productivity, the entrepreneur may pay another fixed cost to form a firm. Firms engage in monopolistic competition and pay fixed and iceberg costs to export goods. The pollution abatement technology can be described in several equivalent ways—one is that firms pay pollution taxes for each unit of pollution they emit and can choose what share of their capital and labor to devote to producing output versus cleaning up pollution.

This model requires relatively few parameters to estimate, but the least studied empirically is the elasticity of substitution between producing goods and producing pollution. The paper estimates this elasticity by using the quasi-experiment of air pollution regulation under the Clean Air Act as an instrumental variable for firm-level data on pollution abatement investments.

Many papers ask how hypothetical future policies would affect outcomes, but this research looks at the past—it observes firms' actual decisions of what to produce, where to export, and how much pollution to emit. It then asks: what changes in environmental regulation, barriers to international trade, and innovation can generate the actual historical data? The paper backs out these historical variables, and then asks how pollution would have evolved under counterfactual scenarios. For example, what if environmental regulation changed following the path inferred for 1990-2008, but barriers to trade and innovation had not changed? Alternatively, what if environmental regulation had not changed over this period, but barriers to trade had evolved along the historical path that was actually inferred?

The paper's general equilibrium decomposition finds that environmental policy accounts for the large majority of the change in pollution emitted from US manufacturing over the period 1990-2008. Trade and productivity appear to account for smaller shares of the total change in emissions. These patterns are similar across all criteria air pollutants.

Passenger vehicles

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environmental and environmental taxes (Bovenberg and Goulder 1996), relationships between fuel economy and exhaust standards (Jacobsen et al. 2021), and others.

A different approach asks how one important but understudied environmental policy has contributed to declines in air pollution emissions from US passenger vehicles (Jacobsen et al. 2021). New data collected for this research show that since the 1960s, when the federal government began regulating exhaust emissions from US vehicles, the air pollution emitted per mile driven for new US light duty vehicles and light duty trucks fell by more than 99 percent. This is an enormous decline, which may exceed well-documented pollution declines for any major sector or country. Similar declines occurred for all three main measured air pollutants. Additional evidence suggests that similar emissions rate declines occurred for used vehicles. By contrast, declines in CO_2 emissions rates per mile from new vehicles are smaller, on the order of 50 percent.

Why have passenger vehicles become so much cleaner? Auto manufacturers have certainly implemented many innovations, but they focus more on increasing power than benefits the environment (Knittel 2011). Additionally, engineers indicate that secular innovation which improves vehicle performance, power, or handling would not tend to decrease vehicle air pollution emissions (Jacobsen et al. 2021).

As an explanation, this research focuses on a single environmental policy—exhaust standards, which set a maximum emissions rate allowed for each US vehicle sold. These standards began in the late 1960s and have since tightened enormously. Exhaust standards are separate from the fuel economy (CAFE) standards that are the subject of much research.

The research estimates difference-in-difference regressions exploiting changes in exhaust standards across classes of vehicles, model years, geography (federal versus California exhaust standards), and pollutants. It looks separately at each of the exhaust standards that the federal government has enforced since the 1960s, generally referred to as Tier 0 (1968-1993), Tier 1 (1994-2003), Tier 2 (2004-2016), and Tier 3 (2017-2025). The regressions also control for a range of other environmental policies, such as inspection and maintenance (smog check) standards, fuel economy regulations, fuel content regulation, gasoline prices and taxes, and ethanol blending.

These regressions find a central role for exhaust standards in explaining the more than 99 percent decline in emissions rates. Point estimates suggest that between half and all of the decrease in pollution is due to exhaust standards. These patterns appear in new vehicle testing data, used vehicle smog check data, and roadside remote sensing data (collected via infrared beams emitted from roadside devices), and have similar magnitude across pollutants.

Synopsis

Here I have described two settings for air pollution—one using a general equilibrium model which uses a describes firm behavior in response to environmental policy to learn about its effects; and another using panel data regressions in a transportation setting where one policy appears to account for most of the trend in pollution. Of course, this discussion says little about explaining trends in drinking or surface water pollution, let alone toxic pollutants or radioactivity.

The first two hypotheses provide positive judgements, while the third is more normative. One could use many criteria for judging policy—efficiency, equity, political feasibility, and others. I now focus on one of these criteria – efficiency – and ask whether policies in these US environmental domains have produced large net benefits.

Hypothesis 3: Air and drinking water policies tend to produce benefits exceeding their costs; evidence for surface water is much less clear.

Since the Reagan Administration, the federal government has undertaken benefit-cost analyses of all major regulations. A review of dozens of these evaluations finds that benefit-cost ratios tend to be high for air pollution, fairly high for drinking water and greenhouse gas regulations, and often below one for surface water regulation. Specifically, for all regulations analyzed in years 1992-2017, the ratio of total benefits to total costs was 12.4 for air pollution, 4.8 for drinking water, 3.0 for greenhouse gases, and 0.8 for surface water policy. Looking at the benefit-cost ratio of the mean policy, or the share of policies with benefits below costs, provide similar conclusions (Keiser and Shapiro 2019b).

Of course, one can question the estimates of benefits in these studies. Most benefits from air pollution regulations are estimated to accrue from preventing premature adult mortality due to changing concentration of particulate matter smaller than 2.5 micrometers ($PM_{2.5}$) (Dominici, Greenstone, and Sunstein 2014). The estimated effect on mortality, however, depends on several studies (e.g., Krewski et al. 2009) that rely largely on observational variation in pollution. In addition, the valuation of the change in mortality depends on the value of a statistical life, which is typically estimated from hedonic wage studies that depend largely on observational variation. Many benefits of surface water pollution regulation are estimated from contingent valuation studies or geographically-focused studies relying on observational comparisons; the importance of omitted variables bias and the internal and external validity of these studies are uncertain (Keiser and Shapiro 2019a). The estimated benefits of drinking water pollution typically come from small studies of how specific pollutants affect mortality, in some cases through extrapolation of high exposure concentrations, and in other cases using toxicological or animal studies.

Similarly, one can question the estimates of costs in these studies for other reasons (Keiser, Kling, and Shapiro 2019). Most of these studies rely on engineering estimates of the costs of installing end-of-pipe pollution control technology. Such engineering estimates can miss changes in market power and the associated penalty to consumers (Buchanan 1969; Ryan 2012), changes in product quality, general equilibrium changes in the prices of goods or services, and the substitutability of the regulated good with leisure; and other types of costs. One interpretation is that common methods of estimating benefits has advanced substantially in the last half century, but methods of estimating costs still rely heavily on engineering estimates, as they did a half century ago.

In short, while federal benefit-cost analyses support the third hypothesis, there is reason to interpret them cautiously. I now discuss two papers that seek to address some of the challenges highlighted above.

Air pollution

One approach to measuring the marginal costs of making air pollution regulation more stringent focuses on an understudied provision of the Clean Air Act which requires that "nonattainment" counties which violate air quality standards may not have a net increase in air pollution emissions from large sources (Shapiro and Walker 2020). The Act requires that large new or retrofitting plants in nonattainment areas which will meaningfully increase pollution emissions must pay an incumbent polluter in the same area to reduce its emissions of the same pollutant by the same amount.

These regulations have led to the creation of over 500 separate pollution "offset" markets (technically, markets for "Emissions Reductions Credits") which differ by pollutant and nonattainment area. For example, regulators operate separate markets for Nitrogen Oxides emissions in the California Bay Area, Nitrogen Oxides emissions in Houston, and Volatile Organic Compounds in Houston.

These markets can help identify the efficiency of regulation because they provide information on the marginal cost of cleaning up air pollution. Consider an incumbent plant deciding whether to abate pollution and so generate offsets it can sell. An incumbent should invest in pollution abatement until the marginal cost of such investment equals the market cost of offsets. Similarly, an entrant which designs a cleaner plant can decrease the cost of offsets it much purchase, and so save on costs. More generally, even in the presence of transaction costs, firms should choose pollution abatement to reflect the marginal cost of abatement

While these offset prices provide information on the marginal costs of abating pollution, a range of atmospheric chemistry, epidemiological, and economic models provide information on the marginal benefits of abating pollution. Together, these sources of information provide a revealed preference way to estimate the marginal costs and benefits of tightening air pollution regulation.

Applying this approach to data on offset prices from 16 states suggests that the marginal benefits of air pollution regulation exceed offset prices more than ten fold on average, though with some exceptions. In Houston, for example, offset prices for VOCs exceed the marginal benefits of cleaning up VOC pollution.

This analysis also compares engineering estimates of marginal abatement costs from the EPA's own software and data against revealed preference estimates from offset prices. These estimates are extremely different, in some cases, by a factor of five or more. While specific patterns seem to explain these discrepancies – for example, abatement technologies and costs for VOCs seems to be outdated – they do suggest caution in relying on engineering estimates of marginal abatement costs.

Water Pollution

Since the 1972 Clean Water Act, public and private sources have spent over $1 trillion to provide clean surface water, or over $100 per person per year. At the same time, over half of rivers and streams violate ambient water quality standards, and Americans have listed water pollution as their top environmental concern in Gallup polls taken since 1989 (Keiser and Shapiro 2019a, 2019b).

To shed light on the costs and benefits of investments made under the Clean Water Act, Keiser and Shapiro (2019a) compile an array of administrative data largely not used before in economics. These include 240,000 pollution readings from over 50,000 monitoring sites across 40 years; a panel census of US wastewater treatment plants, which treat sewage and other municipal wastes before they are discharged to rivers and streams; detailed data on over 35,000 grants the federal government gave cities through the Clean Water Act to upgrade wastewater treatment plants; a survey of industrial water use conducted when the Clean Water Act began, and recently recovered from a decommissioned government mainframe; and others.

The analysis uses generalized triple-difference estimators to compare water pollution downstream versus upstream of these federal grants, in years before versus after grants were provided, and between different wastewater treatment plants. It also reports changes in home values due to these grants.

The paper finds that these Clean Water Act grants substantially decrease water pollution. The average grant cost about $8 million and decreases the probability that downstream waters violate water quality standards to be safe for fishing by 1 to 2 percent. Overall, a cost-effectiveness analysis of these grants suggests that it cost $1 to $2 million to make one mile of a river safe to fish in for one year.

Although the paper finds clear evidence of decreases in water pollution, evidence for increases in home values is mixed. In total, while point estimates suggest that home values increase around surface waters when a grant is received, the increase is only about a fourth of the cost of these grants. The analysis describes a range of reasons why the hedonic model here may provide a lower bound on willingness to pay for water quality improvements, including that households may be unaware of improvements, that distant and nearby households may have non-use value for clean waters, and that cleaning surface waters may produce health benefits that this approach does not quantify.

Research has taken other approaches to measure benefits that this type of application of the hedonic model might miss. One is to look directly at health consequences of improving surface water quality. The standard assumption is that drinking water treatment in the modern US is sufficient to remove health threats that would arise from polluted surface waters. Flynn and Marcus (2021) find that the Clean Water Act grants discussed above increased infant birthweight, though the monetized benefits remain well below the grants' costs. Another is to estimate a joint model of housing and recreational demand; in one setting in Florida at least, this appears to measure larger benefits than a hedonic model alone (Kuwayama, Olmstead, and Zheng 2018).

Synopsis

These analyses of air and water pollution look at an understudied policy, use administrative data on environmental markets, conduct statistical cost-benefit comparisons, and utilize state-of-the-art atmospheric dispersion models.

The first three hypotheses largely address aggregate pollution levels, and in some cases briefly discuss heterogeneity by geography and community characteristics. I now turn to the fourth and final hypothesis, which focuses on a recent literature that uses detailed household and neighborhood data to study the distribution of environmental damages under different policy instruments.

Hypothesis 4: market-based policies and command-and-control policies do not have systematically different effects on the distribution of environmental outcomes and on Environmental Justice concerns.

This hypothesis combines two concepts. One is environmental markets—the use of pollution taxes, cap-and-trade markets, offset markets, or other price-based policies to regulate environmental goods. The advancement of market-based environmental policies has been one of economists' most important contributions to environmental policy. Economists tend to advocate market-based environmental policies because they are cost-effective—they maximize pollution reduction for a given level of expenditure (or, equivalently, the minimize cost for a given level of pollution reduction). Market-based environmental policies can also generate revenues to offset other distortionary taxes (a "double dividend"). They also provide an alternative to more traditional, prescriptive and inflexible policies, often called "command and control" instruments.

The second concept is Environmental Justice. The Environmental Justice movement asserts that environmental policy should be inclusive, participatory, and respectful, and provide fair treatment of all social groups, without regard to race, income, or other demographics. This principle focuses on the process and method of developing policy. The Environmental Justice movement also advocates for policy to provide a more equitable environment. Everyone, the movement argues, should live in a healthy environment that promotes their well-being, regardless of a person's background. A motivating fact behind this movement is that low-income communities and communities of color tend to experience disproportionately high rates of pollution. This pattern occurs for many pollutants, time periods, minority groups, and in many datasets.

A recent concern is that environmental markets exacerbate Environmental Justice concerns. In some cases, this is a concern about the process of developing environmental markets. In other cases, the concern is that markets do not guarantee a distribution of pollution, and it is possible that the introduction of markets would fail to decrease or increase pollution in some areas.

These concerns have growing policy influence. The Biden Administration, for example, highlights Environmental Justice alongside climate change as its top environmental priorities. Both Washington's carbon tax bill and California's cap-and-trade renewal faced serious opposition from some progressive groups due to Environmental Justice concerns. In addition, former California Air Resources Board head Mary Nichols was considered for appointment to the EPA but passed by reportedly in part due to her support for California's AB32 carbon cap-and-trade bill.

Several studies have sought to assess how market-based environmental policies affect the distribution of environmental outcomes. Fowlie, Holland, and Mansur (2012) compare the RECLAIM market for nitrogen oxides in Southern California against a command-and-control counterfactual. They find that RECLAIM substantially decreased NO_x emissions relative to command-and-control and provided similar decreases in emissions for different demographics.

Grainger and Ruangmas (2018) study the same market but examine ambient pollution concentrations rather than emissions. They use a state-of-the-art dispersion model, Hysplit, to translate emissions into ambient concentrations. They find that looking at ambient concentrations rather than emissions leads to somewhat different conclusions and suggest that RECLAIM disproportionately benefitted high-income and white communities.

A third paper, by Hernandez-Cortes and Meng (2020), looks at how California's cap-and-trade market for CO_2 affected air pollution. They consider both emissions and, using the Hysplit dispersion model, ambient concentrations. Rather than focus on differences across communities by race, they consider a set of "disadvantaged zip codes" defined by policymakers and ask how pollution trading affects pollution in these versus other zip codes. They generally find that the market decreases air pollution inequality between advantaged and disadvantaged zip codes.

Another recent paper studies a dozen markets, spread between California and Texas (Shapiro and Walker 2021). This builds on the analysis of offset markets studied above, except it looks at the distribution of environmental damages (equity) rather than aggregate costs and benefits (efficiency). Because an offset represents the permanent right to emit a ton of pollution, one can use offset markets to trace where pollution moves, as incumbent firms sell the permanent right to emit pollution to entrants.

This feature makes it possible to ask whether the communities where offset markets decrease pollution have different demographics than the communities where offset markets increase pollution. In a direct sense, this tests whether offset markets are moving pollution to or from low income communities and communities of color. Shapiro and Walker (2021) implement this test by comparing the demographics of communities selling versus buying offsets.

They find that these communities have similar demographics, which is one piece of evidence that these market-based policies do not substantially change the distribution of pollution across communities. The share of households that are Black or Hispanic, and median household income, are similar for communities where plants sell offsets as for communities where plants buy offsets. This similarity persists across cities, time periods, and pollutants.

Synopsis

Hypothesis 4 represents more of a conjecture than a hypothesis. Analysis of three individual markets in California, and a dozen offset markets in California and Texas, provides a range of results. These results do not find systematic differences in the distribution of environmental damages between market-based policies and command-and-control policies.

At the same time, these results deserve stronger caveats than other hypotheses do. The external validity of these estimates is unknown—demographics, market design, pollution dispersion, and other variables may differ substantially between California and other markets. In addition, the four studies discussed above all have somewhat different methods, approaches to pollution dispersion, measures of inequality and Environmental Justice, and conclusions. These differences complicate generalization. While these studies fail to show systematic differences between market-based and command-and-control policies, I believe they also fail to rule out the possibility that such differences exist more broadly.

Conclusions

I have organized this discussion around four hypotheses describing US pollution over the past several decades. First, air pollution, drinking water pollution, and surface water pollution have declined substantially over recent decades, though CO_2 emissions have not. Second, environmental policy provides a leading explanation for these trends. Third, many air and drinking water policies have produced benefits exceeding their costs; evidence for net benefits of surface water regulation is less clear. Fourth, market-based policies and command-and-control policies do not have systematically different effects on the distribution of environmental outcomes.

The discussion focuses on the US and does not provide a comprehensive literature review. It finds strong evidence for the first hypothesis, good evidence for the second, emerging evidence for the third, and interprets the fourth as more of a conjecture that evidence is beginning to test.

I also try to highlight how some recent advances have helped evaluate these hypotheses. Regulators have collected data on environmental goods to administer policies. Increasing access to these administrative data is helping researchers analyze policy. Many policies discussed here have not been a focus of research until recently and have features which are well suited to testing the four hypotheses. Research is increasingly able to use multiple types of data on pollution – emissions, ambient concentrations, and pollution dispersion models relating emissions and ambient concentrations – which strengthen the evidence. Several settings make it possible to measure costs and benefits in a single framework, and to report hypothesis tests comparing them which do not depends on questions about external validity. In some cases, research has been able to combine transparent research designs of applied microeconomic research, microeconomic models of individual firms and households, and aggregate analysis of the environment in the entire economy to develop micro-macro frameworks. Finally, a nascent literature looks at the distribution of environmental damages from different policy instruments.

I conclude with three topics here that remain open for discussion. First, I have said little about natural resources like timber, fisheries, or groundwater. It is unclear how accurately the hypotheses in this paper describe natural resources, but answering this question would be valuable.

Another question is why CO_2, and potentially natural resources, have different patterns than "local" pollutants like air and water pollution. Political economy is not traditionally the focus of environmental economics research—papers are more likely to point out the inefficiency of a policy than to study the politics of why an inefficient policy was implemented. While there are some obvious answers – the climate is a global public good subject to a severe free rider problem, and regulating local pollutants provides immediate local benefits – better understanding the political economy of efficient environmental policy has academic and practical benefits.

Finally, much economic research on Environmental Justice focuses on how different policies affect outcomes, like the distribution of environmental damages (Hsiang, Oliva, Walker 2019). While that is important, it also abstracts from the political economy of how policy is developed. Perhaps process questions fit more naturally in political science than economics, but political economy research in other domains has studied the process of policy development (e.g., Bagwell, Staiger, and Yurukoglu 2020), and perhaps there are similar insights to gain for environmental policy.

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