# Pollution Trends and US Environmental Policy: Lessons from the Last Half Century [1]

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Abstract

This article proposes and evaluates four hypotheses about US pollution and environmental policy over the last half century. First, air and water pollution have declined substantially, although greenhouse gas emissions have not. Second, environmental policy explains a large share of these trends. Third, much of the regulation of air and drinking water pollution has benefits that exceed costs, although the evidence for surface water pollution regulation is less clear. Fourth, while the distribution of pollution across social groups is unequal, market-based environmental policies and command-and-control policies do not appear to produce systematically different distributions of environmental outcomes. I also discuss recent innovations in methods and data that can be used to evaluate pollution trends and policies, including the increased use of environmental administrative data, statistical cost-benefit comparisons, analysis of previously understudied policies, more sophisticated analyses of pollution transport, micro-macro frameworks, and a focus on the distribution of environmental outcomes.

JEL Codes: Q50, Q58, H23

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## INTRODUCTION

In the 1960s and early 1970s, concerns about the US environment grew rapidly. Many events contributed to these concerns, including the publication of Rachel Carson's (1962) *Silent Spring*, photographs 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 concerns was a fear that despite growing prosperity after World War II, environmental degradation driven by industrialization threatened to undermine US quality of life. The controversial *Limits to Growth* report (Meadows et al. 1972) reflected the prevailing fears of the time by describing a future where pollution would grow exponentially for a century.

Together, these events fostered enormous support for US environmental policy. In response, in the early 1970s, the federal government created the Environmental Protection Agency (EPA) 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 of Representatives approved the 1972 Clean Water Act by a vote of 247-23.

A half century has passed since enactment of these laws, making this is a good time to step back and review the lessons learned from 50 years of environmental policy and economic research. This article presents and discusses the evidence for four general hypotheses that summarize trends in US pollution and environmental policy outcomes over the last half century:

- Hypothesis 1: Air pollution, drinking water pollution, and surface water pollution have declined substantially over the last several decades, although $CO_2$ emissions have not.
- Hypothesis 2: Environmental policy explains a large share of long-term decreases in air and water pollution.

- Hypothesis 3: Air and drinking water policies have tended to produce benefits that exceed their costs; the evidence for surface water is much less clear.
- Hypothesis 4: While the distribution of pollution across social groups is unequal, market-based policies and command-and-control policies do not have systematically different effects on the distributions of environmental outcomes.

I emphasize that these are hypotheses, not theses. For each hypothesis, I highlight examples of the existing evidence that supports or opposes it. For Hypothesis 1, I find that the evidence for air, surface water, and $CO_2$ trends is strong, while the evidence for drinking water trends is less clear. For Hypothesis 2, comprehensive evidence is not available, and thus I focus on suggestive evidence from specific settings. For Hypothesis 3, I focus on evidence concerning air pollution, although I also discuss the more limited evidence on surface water pollution. For Hypothesis 4, the research is still emerging; thus, less evidence is available to evaluate this hypothesis than the others.

I also highlight recent innovations in methods and data that have improved researchers' ability to test these hypotheses and that can be used to evaluate pollution trends and environmental policies:

- **Administrative data on environmental goods.** Administrative data are generally collected to administer a policy, but scholars are increasingly using these detailed data for research (e.g., Keiser and Shapiro 2019a).
- **Statistical cost-benefit tests**. Some studies estimate confidence intervals for estimates of differences between benefits and costs, which allow the researcher to draw statistical conclusions about whether benefits exceed costs (e.g., Greenstone and Gallaher 2008; Keiser and Shapiro 2019a).

- **Focus on important but understudied policies**. Some policies have played critical roles in US environmental policy over the last half century, but until recently, have not been a focus of research (e.g., Jacobsen et al. 2021; Shapiro and Walker 2021).
- **More sophisticated models of pollution transport**. Researchers are using improved scientific models and data that describe how pollution emissions in one location affect ambient pollution[2] concentrations in other locations (e.g., Keiser and Shapiro 2019a; Flynn and Marcus 2021; Jerch 2021).
- **Micro-macro frameworks**. Recent economics research combines detailed microdata on individual firms and households, clear identification of key parameters, and models of firm and consumer optimization behavior, and then sums pollution across firms to learn about outcomes for an entire sector or the entire economy (e.g., Shapiro and Walker 2018).
- **Focus on the distribution of environmental outcomes**. While there has long been research on the distributional consequences of economic policy, a recent strand of the literature focuses specifically on the effects of policy on the locations where pollution is emitted and its impacts on environmental quality (e.g., Fowlie, Holland, and Mansur 2012; Grainger and Ruangmas 2018; Hernandez-Cortes and Meng 2021; Shapiro and Walker 2021).

A few additional caveats are in order. First, this article provides only a limited review of environmental and energy economics. In particular, it focuses disproportionately on research in which I have directly participated, focuses almost exclusively on the US, and mostly excludes consideration of natural resources like fisheries, forests, biodiversity, and groundwater. I do not consider these goods, in part, because many studies of resources examine a single watershed, county, ecosystem, or other individual

[2] Ambient pollution refers to the level of pollution that people experience, typically measured by air quality monitors, water quality monitors, or similar devices. It contrasts with pollution emissions, which represent the level of pollution that firms emit, and with pollution damages, which represents the level of economic, health, and other costs that people incur due to ambient pollution levels.

setting, which makes it difficult to draw general conclusions about national trends and the impacts of broad national policies.[3] Moreover, other articles extensively review the literature on several of the individual issues and policies that I discuss here.[4] In contrast, my objective here is to provide a broader overview of pollution trends, policy impacts, and distributional consequences, which might be overlooked in a single research paper or when examining a single policy, pollutant, or method in isolation.

## HYPOTHESIS 1: AIR POLLUTION, DRINKING WATER POLLUTION, AND SURFACE WATER POLLUTION HAVE DECLINED SUBSTANTIALLY OVER THE LAST SEVERAL DECADES, ALTHOUGH $CO_2$ EMISSIONS HAVE NOT

Data collected since the 1960s for surface water pollution, the 1970s for air pollution, and the 1980s for drinking water pollution reveal large and sustained declines. By contrast, long-run data on $CO_2$ emissions reveal steady increases through the year 2008, followed by a flattening, and then perhaps slight decreases.

Why should an economics article examine trends in purely environmental goods like air and water pollution at all? Although measuring these trends generally uses hydrology, atmospheric chemistry, environmental engineering, and other fields outside economics, the accurate measurement of environmental goods is a prerequisite for the types of tasks that economists might undertake, including analyzing consumer preferences, firm technologies, policy design, and the impacts of counterfactual policies. Thus, accurate measurement of environmental goods is a critical input to the economic analysis of them. This section discusses recent progress on measuring trends in several environmental

[3] However, increased access to – and increased quality of – remote sensing data is enabling national and global analysis of timber, groundwater, and other natural resources.
[4] For some relevant reviews, see Olmstead (2010) and Keiser and Shapiro (2019b) on water quality, Currie and Walker (2019) on air quality, and Hsiang, Oliva, and Walker (2019) on the distribution of environmental damages.

goods, including air pollution; surface water pollution; drinking water pollution; toxic pollution; and greenhouse gases.

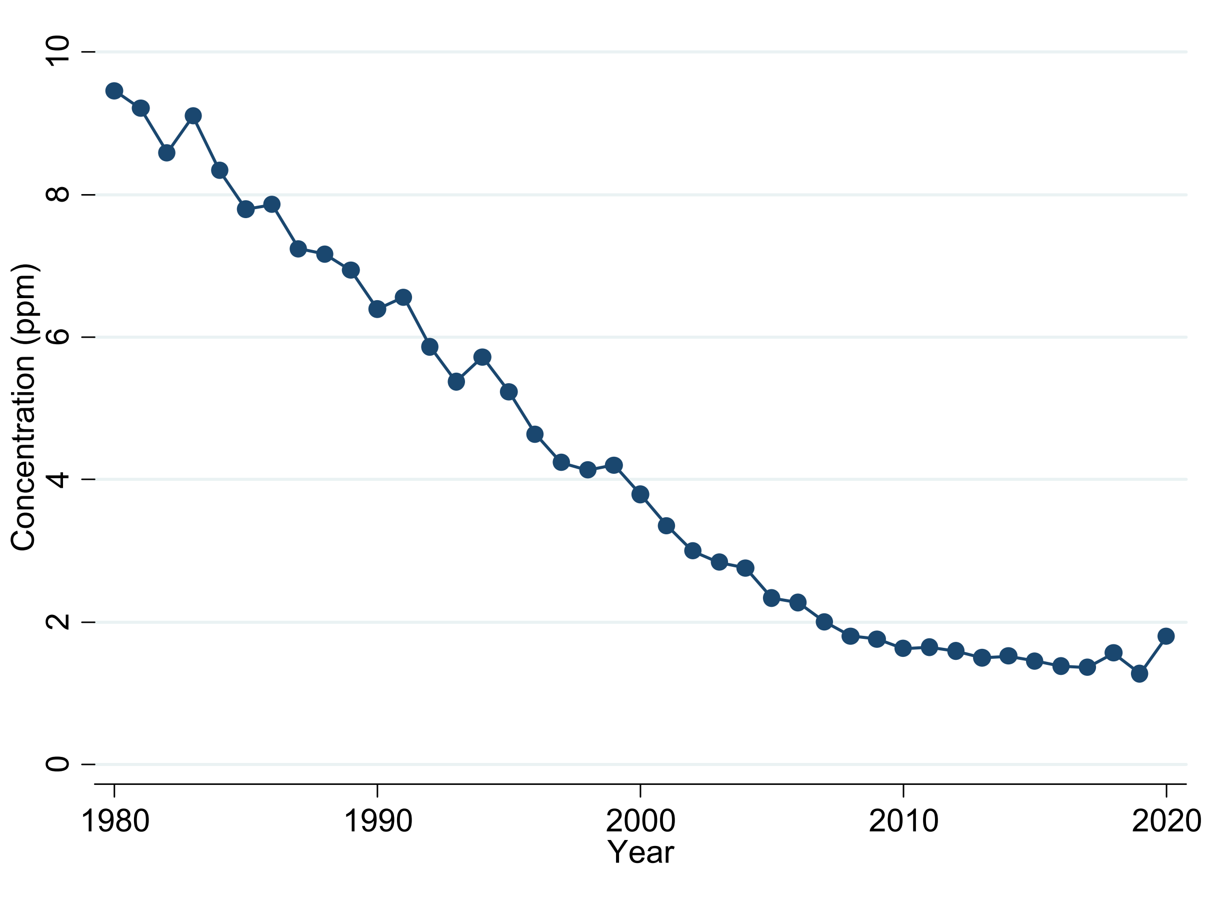
## Evidence on Trends in Air Pollution

Data on the main air pollutants regulated by the Clean Air Act (known as "criteria" pollutants) are readily available because the EPA, as well as some individual states (e.g., California), maintain organized networks of monitors.[5] These monitors are operated in part to assess whether counties violate air quality standards; that is, the data are collected partly for administering the policy. However, these data are also useful for research on emissions trends.

Indeed, the data indicate that ambient concentrations of some air pollutants have fallen dramatically in recent decades. Between 1980 and 2019, concentrations of carbon monoxide, lead, and sulfur dioxide each fell by more than 80 percent; there have been similar declines in particulate matter, but ground-level ozone concentrations have fallen by only a third (USEPA 1980; Chay and Greenstone 2005; USEPA 2021a). Figure 1 illustrates the trends for carbon monoxide concentrations, using the EPA's standard measure of this pollutant (parts per million, or ppm).

**Figure 1: Carbon Monoxide Trends, 1980-2020**

[5] The "criteria pollutants" under the Clean Air Act include particulate matter, photochemical oxidants (e.g., ozone), carbon monoxide, sulfur oxides, nitrogen oxides, and lead (https://www.epa.gov/criteria-air-pollutants, visited 10/10/21).




Source: USEPA https://www.epa.gov/air-trends/carbon-monoxide-trends , visited 9/14/2021

Measuring air pollution emissions from individual sources, 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, and management quality. Some estimates of emissions come from engineering calibrations, while others come from direct measurement of a plant's smokestack. Nevertheless, reported emissions rates from industrial, transportation, and other sources indicate declines that are of generally similar magnitudes to those for ambient concentrations. For example, between 1980 and 2019, emissions of carbon monoxide and sulfur dioxide fell by 75 percent and 92 percent, respectively (USEPA 2021b).

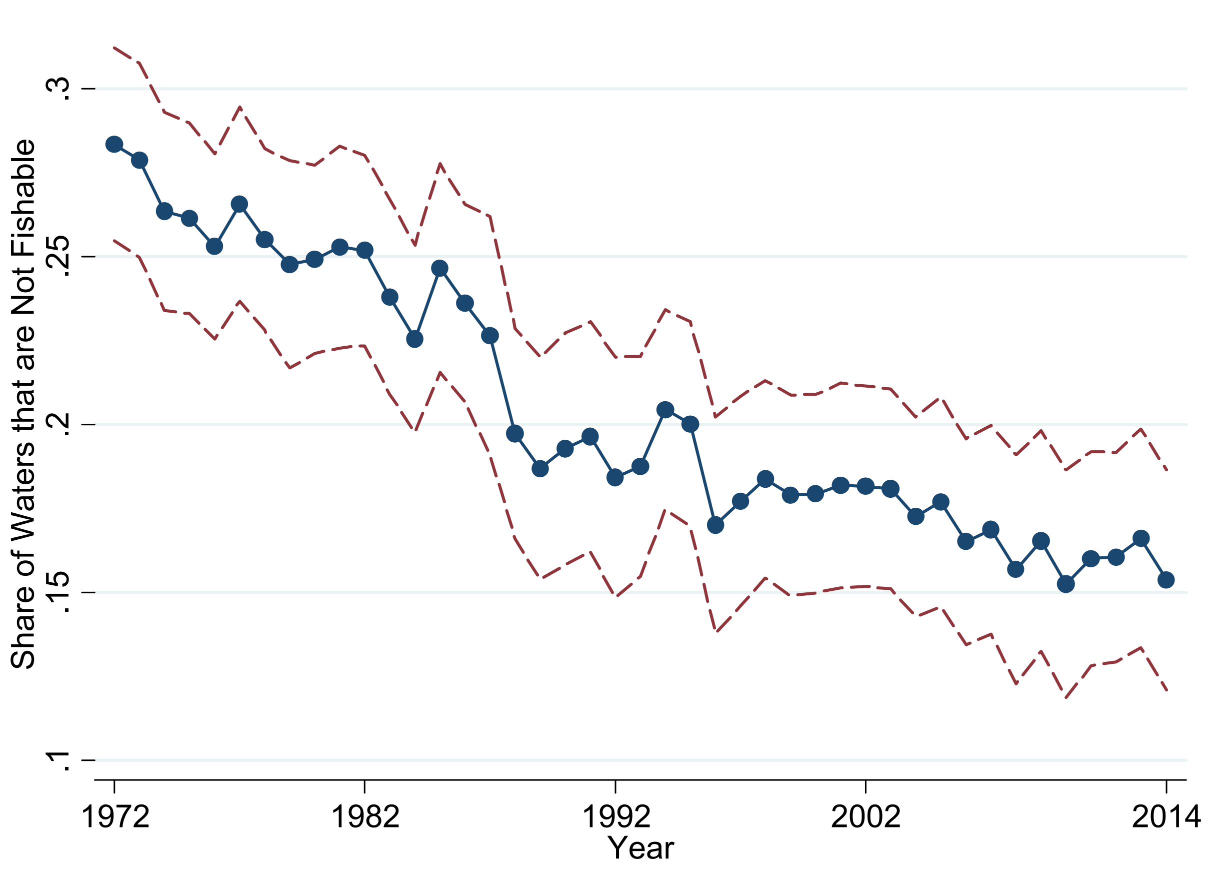
**Evidence on Trends in Surface Water Pollution**

Measuring pollution trends in rivers, lakes, and other surface waters is more challenging than measuring trends in air pollution. This is because most data on surface water quality are collected by state and local organizations, including a large share from state offices of the US Geological Survey. The recent creation of the Water Quality Portal[6] by the EPA, the U.S. Geological Survey, and the National Water Quality Monitoring Council has enhanced researchers' ability to access and analyze semi-recent water quality data.

The most common indicators of surface water pollution have decreased substantially since the 1970s. For example, between 1972 and 2014, fecal coliforms (a measure of bacteria associated with human and animal wastes) fell by about two-thirds. Total suspended solids (a measure of the total particles suspended in water), which reflects a wide range of pollutants, fell by about a third over the same period (Keiser and Shapiro 2019b). As shown in Figure 2, there has been a similar declining trend in the share of waters that are unsafe for fishing, which is a common measure of water quality that aggregates data for these and other pollutants.[7]

[6] See waterqualitydata.us. Older water quality data are available through a retired repository, Storet Legacy.
[7] Under this definition, a water body is fishable if its levels of four commonly measured water pollutants – biochemical oxygen demand, dissolved oxygen saturation, fecal coliforms, and total suspended solids – fall below prescribed limits.

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




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

However, 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. Thus, the trends for nutrients are generally much flatter and, for some pollutants, they are actually increasing (Keiser and Shapiro 2019a).

I do not discuss emissions data for surface water pollution because they are less comparable over time. In particular, although large water pollution sources report quarterly emissions to the EPA, different sources use different approaches to measurement, including reporting concentration versus total quantity, one versus many monitoring sites, different reporting frequency, and different pollutants. This makes it difficult to construct representative and comparable trends in surface water pollution emissions.

**Evidence on Trends in Drinking Water Pollution**

Measuring trends in drinking water pollution is also difficult. The US has approximately 150,000 drinking water systems. About one-third are community water systems that serve households and institutions like campgrounds and gas stations. Most community water systems directly or indirectly monitor the roughly 95 contaminants that are regulated by the Safe Drinking Water Act. However, the EPA does not require these systems to report pollution concentrations to federal regulators. Local drinking water systems do report the number of violations of drinking water standards to federal regulators, with a violation indicating that a reading exceeds the standard or that required procedures have not been followed. The EPA keeps records of such violations in a federal database, the Safe Drinking Water Information System.

Many studies seek to measure violations using the federal database, although two issues make it harder to infer actual pollution trends from those data. First, drinking water standards change and are frequently tightened. This makes it unclear whether an increase in violations represents a decrease in absolute water quality or an increase in the water quality standards. Second, many drinking water systems have historically failed to report violations to the federal database, which means its coverage is incomplete, varies over time, and is potentially biased.

Allaire, Wu, and Lall (2018) rely on a large sample of drinking water utilities that report violations to the federal database every year. The data in this sample indicate that when the Safe Drinking Water Act tightens standards, the number of violations increases. However, the authors find that after those initial increases, there is a steady downward trend in violations. Although far from conclusive, these patterns suggest that drinking water quality has been improving.

**Evidence on Trends in Toxic Pollution**

Data from the Toxics Release Inventory (TRI) show sustained and large declines in emissions of many types of toxic pollution to water, air, and land.[8] However, there have been concerns about data quality. In particular, the data fail some data quality tests; it can be unclear how to appropriately aggregate totals across many different pollutants; and firms may misreport emissions. In addition, emissions differ from ambient concentrations, and ambient monitoring of toxic pollutants is limited (Currie et al. 2015). Nonetheless, the TRI data suggest large and sustained declines in US toxic pollution emissions since 1989, when the TRI began collecting data.

**Evidence on Trends in Greenhouse Gases**

Greenhouse gases are global pollutants. This means that their social cost depends on the quantity of global emissions, not the location from which the pollution is emitted. Thus, the damage from climate change does not depend on whether emissions come from the US or other countries.

[8] The EPA compiles the TRI, which requires large US sources of toxic pollution to report their physical emissions of a large list of different toxic chemicals. Toxic chemicals, sometimes called hazardous chemicals, include over 100 harmful chemicals (such as arsenic compounds, benzene, and cyanide compounds) that are not classified as criteria pollutants.

Nonetheless, it is useful to examine US emissions over time, and such data are readily available from the EPA (e.g., the Inventory of US Greenhouse Gas Emissions and Sinks).

These data show steady increases in US $CO_2$ emissions through 2008, followed by a gradual decline through 2021 (USEPA 2021c). The decline that occurred immediately after 2008 was likely due to the Great Recession. However the continued decline has more likely been due to falling U.S. natural gas prices caused by hydraulic fracturing (fracking), which has resulted in the substitution of natural gas for coal in electricity generation (Fell and Kaffine 2018; Johnsen, LaRiviere, and Wolff 2019). While one could argue about the extent to which public subsidies to energy research, policies that increase the cost of coal, and other forces led to the expansion of fracking in the late 2000s, they have clearly resulted in decreased US $CO_2$ emissions. At the same time, the decrease in US $CO_2$ emissions has been much smaller than the decrease in air, surface water, or (likely) drinking water pollution.

**Summary**

The data I have presented here appear to support Hypothesis 1. That is, the air and water pollutants whose concentrations are measured have declined substantially in recent decades, much more than $CO_2$ emissions. However, for several reasons, these findings should be interpreted with caution. First, US industry produces or processes thousands of chemicals, many of which have potential health implications, but the Safe Drinking Water Act only regulates about 95 these chemicals.[9] Second, because the pollutants that are regulated tend to be those that are monitored, it is possible that unregulated pollutants have declined less than regulated pollutants. Third, I have not discussed radioactivity, noise, light, or other externalities, which are clearly important but have received less attention from economists.

[9] For comparison, the Clean Air Act regulates 187 toxic chemicals.

The finding that air pollution emissions are declining much more than $CO_2$ emissions suggests that it is important to consider how these two types of pollution interact. For example, some researchers argue that reducing $CO_2$ emissions decreases air pollution emissions (e.g., Vandyck et al. 2018). Such a "co-benefit" would occur, for example, if $CO_2$ reductions came from switching from coal to natural gas combustion, from fossil fuels to renewable energy, or from decreasing energy demand. It makes sense to ask if this pattern is symmetric; that is, whether policies that directly target decreases in air (or water) pollution indirectly cause decreases in $CO_2$ emissions. In theory, the impacts are not clear. For example, air or water pollution might decrease due to end-of-pipe abatement technologies like scrubbers, which do not affect $CO_2$ emissions, or $CO_2$ emissions might increase because of the energy required to operate these technologies (the "heat rate penalty"). Alternatively, air or water pollution policy might decrease combustion of coal or all fossil fuels, which would decrease $CO_2$ emissions. The evidence presented in this section provides some insights for comparing these views of co-benefits.

Finding large decreases in air pollution but little trend for $CO_2$ appears to be consistent with the idea that overall, polices that decrease local pollutants do not decrease $CO_2$. This aggregate result is also consistent with quasi-experimental analyses that find that local U.S. air pollution policies do not decrease greenhouse gas emissions (Deschenes, Greenstone, and Shapiro 2017; Brunel and Johnson 2019).

## HYPOTHESIS 2: ENVIRONMENTAL POLICY EXPLAINS A LARGE SHARE OF LONG-TERM DECREASES IN AIR AND WATER POLLUTION

Why have air and water pollution declined substantially but $CO_2$ has not?  One could imagine several explanations for these pollution trends. Perhaps these patterns reflect trade and outsourcing; for example, dirty industries and their products might increasingly be located and produced in Mexico, China, and other countries with weaker regulation, and then imported into the US. Perhaps productivity growth has enabled firms to produce more output while using fewer polluting inputs like coal. Perhaps structural transformation -- the gradual shift of an economy from agriculture to manufacturing to services -- has led to the concentration of production in cleaner industries. Perhaps consumer preferences have shifted towards cleaner goods, due to either "warm glow" demand for environmentally friendly products or people devoting more expenditure to cleaner goods for reasons not specifically related to the environment.[10]

While many studies examine environmental policies one-at-a-time to assess their consequences, Hypothesis 2 refers more broadly to the aggregate effect of all environmental policies.[11] Thus, this hypothesis can benefit from an approach that combines the credible and transparent research designs of applied microeconomics with the broad approach of many macroeconomic analyses. In this section, I describe two settings – manufacturing and passenger vehicles – where research exploits natural experiments and data on individual pollution sources and then applies an economy-wide model to assess what the regulation of these individual sources means for pollution in the economy overall. I show that for both settings, the evidence appears to support the hypothesis that environmental policy has been the dominant driver of the decrease in pollution. I do not discuss the role of policy in explaining trends in drinking or surface water pollution, toxic pollutants, or radioactivity.

**Empirical Research on Manufacturing**

One strand of the literature focuses on air pollution emissions from US manufacturing. Shapiro and Walker (2018) show that 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 enabled

[10] "Warm glow" denotes the concept that people derive utility directly from helping other people or the environment.

[11] 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, including looking at interactions of non-environmental and environmental taxes (Bovenberg and Goulder 1996) and relationships between fuel economy and exhaust standards (Jacobsen et al. 2021).

firms to produce more output while emitting less air pollution? Environmental policy, trade, and productivity growth provide three potential explanations.

One influential set of studies has decomposed changes in pollution into three channels: "scale" (changes in output), "composition" (changes in the share of output accounted for by different industries), and "technique" (changes in the physical amount of pollution emitted per dollar of goods produced in each industry). These studies find that in many high income countries, air pollution has declined and that this decline generally appears to reflect technique rather than composition effects (Levinson 2009, 2015; Cherniwchan, Copeland, and Taylor 2017). While this suggests that reallocation of production across industries is not the primary driver of decreases in pollution, it does not identify specific economic forces or policies that have caused the change in technique.

One way to compare the importance of environmental policy versus other forces is to examine a microeconomic model of firm behavior that is aggregated to describe economy-wide trends (Shapiro and Walker 2018).[12] To estimate this model empirically, Shapiro and Walker (2018) estimate the cost to firms of cleaning up pollution by using air pollution regulation under the Clean Air Act as the source of variation in firm-level investments in pollution abatement. They find that environmental policy accounts for most of the changes in pollution emitted from US manufacturing over the 1990-2008 period, with trade and productivity appearing to account for smaller shares of the total change in emissions. These patterns are similar across all criteria air pollutants.

**Empirical Research on Passenger Vehicles**

Another methodology examines how one important but understudied environmental policy – the regulation of exhaust emissions – has contributed to declines in air pollution emissions from US

[12] This model weaves together features of the Melitz (2003) framework, which describes a mathematical model of heterogeneous firms engaging in monopolistic competition, and the Copeland and Taylor (2003) pollution framework, which describes output as a Cobb-Douglas function of pollution and other factors of production (although their pollution framework has other equivalent interpretations).

passenger vehicles (Jacobsen et al. 2021). New data analyzed by Jacobsen et al. (2021) indicate 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 has fallen by more than 99 percent. This is an enormous decline, which may exceed the pollution declines for any major sector or country. The authors find similar declines for all three of the main measured air pollutants (i.e., carbon monoxide, nitrogen oxides, and volatile organic compounds). Jacobsen et al. (2021) also find evidence of similar emissions rate declines for used vehicles. By contrast, declines in $CO_2$ emissions rates per mile from new vehicles were smaller, on the order of 50 percent between the 1960s and 2010s.

Why have passenger vehicles become so much cleaner? Auto manufacturers have certainly implemented many innovations, but these innovations have focused more on increasing power than on benefiting the environment (Knittel 2011). Additionally, engineers argue that innovation that improves vehicle performance, power, or handling would not typically decrease vehicle air pollution emissions (Jacobsen et al. 2021). Trade cannot directly explain this pattern either, because one cannot import transportation services, for example, from Los Angeles to San Francisco. However, changing vehicle attributes that are due to increased imports of vehicles from Japan and elsewhere could play some role in explaining the decline in vehicle emissions.

Jacobsen et al. (2021) focus on a single environmental policy – exhaust standards – as an explanation for the decrease in emissions rates from new US vehicles. These standards, which set a maximum allowable emissions rate for each US vehicle sold and are separate from the widely-studied fuel economy (CAFE) standards, began in the late 1960s and have been significantly tightened since then.

Jacobsen et al. (2021) analyze variation between light-duty vehicles and light-duty trucks, across model years, between federal and California exhaust standards, and across the three main regulated pollutants (carbon monoxide, nitrogen oxides, and hydrocarbons). The analysis separately examines each of the exhaust standards that the federal government has enforced since the 1960s and controls 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. Jacobsen et al. (2021) find that exhaust standards play a central role in explaining the more than 99 percent decline in emissions rates. In fact, point estimates suggest that between half and all of the decrease in pollution is due to exhaust standards.[13]

### Relationship with the First Hypothesis

The second hypothesis is clearly connected to the first hypothesis. Air, surface water, and drinking water pollution produce immediate negative and local externalities, which provide local residents with an incentive to pressure policymakers to control them. This is one of the main reasons that stringent environmental policies have targeted these pollutants. However, because $CO_2$ emissions produce global negative externalities, local residents have a weaker incentive to address them. This at least partially explains why $CO_2$ policy has been weaker and thus the declines in $CO_2$ have been smaller than the declines in air and water pollution.

## HYPOTHESIS 3: AIR AND DRINKING WATER POLICIES HAVE TENDED TO PRODUCE BENEFITS THAT EXCEED THEIR COSTS; THE EVIDENCE FOR SURFACE WATER IS MUCH LESS CLEAR

The first two hypotheses have provided positive judgements about pollution trends and their causes, while the third hypothesis is more normative. One could use many criteria for judging policy, such as

[13] Jacobsen et al. (2021) analyze the relative importance of the exhaust and Corporate Average Fuel Economy (CAFE) standards in decreasing air pollution emissions from passenger transportation. The regression results suggest that if CAFE standards had not been implemented, tightening the exhaust standards would have decreased emissions per mile by 50 to 99 percent. If the exhaust standards had not been implemented, tightening CAFE standards would have decreased gasoline consumption per mile by roughly half and the decrease in gasoline alone would decrease emissions per mile by about half. This suggests that each of these policies alone would have been sufficient to decrease emissions, although the decrease from exhaust standards alone would be much larger.

efficiency, equity, or political feasibility. Here I focus on efficiency and examine whether the evidence indicates that US environmental policies for air and water have indeed produced benefits that exceed their costs.

**Benefit-Cost Analysis in Federal Regulation**

Since the Reagan Administration implemented Executive Order 12291 in 1981, the federal government has required benefit-cost analyses of all major regulations. A recent review of dozens of these analyses 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 (Keiser and Shapiro 2019b). More specifically, the review finds that for all regulations analyzed between 1992 and 2017, the ratio of total estimated benefits to total estimated costs was 12.4 for air pollution, 4.8 for drinking water, 3.0 for greenhouse gases, and 0.8 for surface water policy. These statistics represent the ratio of total benefits to total costs (which gives greater weight to larger policies), but the findings are similar when the review looks at the average policy (which gives greater weight to smaller policies) or the share of policies with benefits below costs.

Of course, one can question the accuracy of the benefits estimates in these regulatory analyses. In the case of air pollution regulations, most of the benefits are estimated to result from the prevention of premature adult mortality due to changing concentrations of particulate matter smaller than 2.5 micrometers ($PM_{2.5}$) (Dominici, Greenstone, and Sunstein 2014). These estimates are based on several epidemiological studies (e.g., Krewski et al. 2009) that rely largely on time-series, cross-sectional, or cross-cohort variation in pollution. In such analyses, it can be difficult to determine the extent to which pollution may be correlated with unobserved determinants of health such as income. However, quasi-experimental studies of specific groups in specific locations, such as US seniors and Chinese households, obtain estimates of mortality impacts due to particulates that are similar in magnitude to those in epidemiological studies (Ebenstein et al. 2017; Sanders, Barreca, and Neidell 2020). In addition, the monetary equivalent of the change in mortality depends on the value of a statistical life, which is typically estimated from statistical correlations of the wages that different industries pay with the fatality risk that workers in those industries face. These studies depend largely on cross-sectional or time-series variation (e.g., Viscusi and Aldy 2003).[14]

In the case of surface water pollution, many of the benefits of regulation have been estimated in contingent valuation studies or geographically-focused studies that compare pollution variation over time and space, but these studies typically use observational variation in pollution (i.e., they do not use a natural experiment or other specific changes in pollution that result directly from policies or other well-understood causes).[15] Thus, it is unclear whether these studies have issues of omitted variable bias and internal and external validity (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 others through the use of toxicological or animal studies.

One can also question the estimates of costs in these regulatory analyses (Keiser, Kling, and Shapiro 2019). Most of these analyses rely on engineering estimates of the costs of installing end-of-pipe pollution control technology. However, such engineering estimates may not include 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, as well as other types of costs.

Thus, although common methods for estimating the benefits of environmental quality have advanced substantially in the last half century, the methods for estimating costs continue to rely heavily on

[14] The value of a statistical life represents a typical individual's willingness to pay (or valuation) for reductions in mortality risk.
[15] In contingent valuation studies (a type of stated preference method), researchers ask people to state their willingness to pay for environmental quality improvements.

engineering estimates, as they did a half century ago. This suggests that while federal benefit-cost analyses appear to support the third hypothesis, the results of these analyses should be interpreted with caution. Below I discuss two studies that seek to address some of the challenges of estimating the benefits and costs of environmental regulation.

**Air Pollution: Benefits Versus Costs**

Shapiro and Walker (2020) use an approach to estimating the marginal costs of increasing the stringency of air pollution regulation that focuses on an understudied provision of the Clean Air Act that prohibits "nonattainment" counties (i.e., those that violate air quality standards) from having a net increase in air pollution emissions from large sources. More specifically, the Act requires that large new or retrofitted plants in nonattainment areas that will substantially increase pollution emissions pay an existing polluting plant in the same area to reduce its emissions of the same pollutant by the same amount; these payments for reductions are known as "offsets."

These regulations have led to the creation of over 500 separate pollution "offset" markets,[16] which differ by pollutant and nonattainment area. For example, regulators operate separate markets for nitrogen oxide emissions in the California Bay Area, nitrogen oxide emissions in Houston, and volatile organic compounds in Houston.

These offset markets can help identify the efficiency of regulation because they provide information on the marginal cost of cleaning up air pollution. Thus, Shapiro and Walker (2020) consider an incumbent (i.e., pre-existing) plant deciding whether to abate pollution in order to generate offsets that it can sell. Economic theory indicates that an incumbent will invest in pollution abatement until the marginal cost of the investment equals the market cost of offsets. More generally, even in the presence of transaction costs, firms should choose pollution abatement to reflect the marginal cost of abatement.

[16] Technically, these are known as markets for "Emissions Reductions Credits."

As Shapiro and Walker (2020) discuss, both the true marginal abatement costs and estimates of them constructed from offset markets depend on other pre-existing environmental and industrial regulations, such as environmental standards and state regulation of electricity markets. In other words, other policies affect both marginal abatement costs and offset prices.

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 method for estimating the marginal costs and benefits of tightening air pollution regulation.

Applying this approach to data on offset prices from 16 states, Shapiro and Walker (2020) find that the marginal benefits of air pollution regulation exceed offset prices by more than ten-fold on average (although there are some exceptions).[17] This suggests that the regulations they study are less stringent than would be optimal.

**Water Pollution: Benefits Versus Costs**

Since passage of 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 (Keiser and Shapiro 2019a). Nevertheless, more than half of US rivers and streams violate ambient water quality standards and in Gallup polls conducted since 1989, Americans have listed water pollution as their top environmental concern (Keiser and Shapiro 2019a, 2019b).

To shed light on the costs and benefits of investments made due to the requirements of the Clean Water Act, Keiser and Shapiro (2019a) compile an extensive set of administrative data that have generally not been used in economics. These data include 240,000 pollution readings from over 50,000

[17] In Houston, for example, offset prices for volatile organic compounds exceed the marginal benefits of cleaning up pollution.

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 lakes; detailed data on over 35,000 grants the federal government has awarded to cities through the Clean Water Act to upgrade wastewater treatment plants; and a survey of industrial water use conducted when the Clean Water Act began. The analysis compares water pollution downstream and upstream of the locations of the federal grants, in years before and after the grants were awarded, and between different wastewater treatment plants. It also examines changes in home values due to these grants.

Keiser and Shapiro (2019a) find that these Clean Water Act grants substantially decreased water pollution. With an average grant project cost of about $8 million, the grants reduced the probability that downstream waters would violate water quality standards for safe 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 for fishing for one year.

Although Keiser and Shapiro (2019a) find clear evidence of decreases in water pollution, the evidence concerning home values is mixed. Overall, while point estimates suggest that home values increase near surface waters when a grant is received, the increase is only about one-quarter of the average cost of these grants. Statistical cost-benefit tests reject the hypothesis that the increase in housing values equals the cost of these grants, but generally fail to reject the hypothesis that the increase in housing values is zero. The authors discuss why home values may provide a lower bound on willingness to pay for water quality improvements, including that households may be unaware of such 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.

Other approaches have been used to measure benefits of improving surface water quality that might be overlooked in an analysis of housing markets. One approach directly examines the health consequences of improving surface water quality and tests the common assumption that the treatment of drinking water in the modern US is sufficient to remove the health threats from polluted surface waters. Using such an approach, Flynn and Marcus (2021) find that the Clean Water Act grants discussed above increased infant birthweight, although the monetized benefits remain well below the grants' costs. Another approach estimates a joint model of housing and recreational demand; Kuwayama, Olmstead, and Zheng (2018) find that in Tampa Bay, Florida, this approach appears to measure larger benefits from surface water quality improvements than a hedonic model alone, suggesting that relying exclusively on an analysis of how water quality affects home values could understate the total benefits of water quality.

**Comparisons between Hypotheses**

The first and third hypotheses offer a striking 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 described by the first hypothesis, one might wonder at what point the marginal cost of cleaning up pollution rises enough to equal its benefits. With this in mind, the third hypothesis suggests that despite large and increasing pollution control, the benefits of some marginal environmental improvements have continued to exceed their costs for air pollution, although the situation for surface water pollution is less clear.

## HYPOTHESIS 4: WHILE THE DISTRIBUTION OF POLLUTION ACROSS SOCIAL GROUPS IS UNEQUAL, MARKET-BASED POLICIES AND COMMAND-AND-CONTROL POLICIES DO NOT HAVE SYSTEMATICALLY DIFFERENT EFFECTS ON THE DISTRIBUTIONS OF ENVIRONMENTAL OUTCOMES

The first three hypotheses largely address aggregate pollution levels and, in some cases, briefly consider geographic and community heterogeneity. The fourth and final hypothesis focuses on a recent literature that uses detailed household and neighborhood data to analyze the distribution of environmental damages under market-based versus command-and-control policy instruments.

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

According to the EPA, "[E]nvironmental Justice is the fair treatment of and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys: The same degree of protection from environmental and health hazards; and equal access to the decision-making process to have a healthy environment in which to live, learn and work" (USEPA 2021d). A key finding that motivates 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, and minority groups.

Some community and political groups have argued that environmental markets exacerbate Environmental Justice concerns. Indeed, both the carbon tax proposal (Initiative 732) that voters in the State of Washington rejected in 2016 and the renewal of California's carbon cap-and-trade legislation in 2017 (AB 398) faced serious opposition from some progressive groups because of Environmental Justice concerns (e.g., Brown 2020). In addition, Mary Nichols, the former head of the California Air

Resources Board, was initially considered by the Biden administration as a candidate for the position of EPA Administrator, but her candidacy was dropped, reportedly in part due to her key role in California's original carbon cap-and-trade bill (AB32) (Davenport 2020). In some cases, the concern has been about the process of developing environmental markets, while in others, the concern has been that markets do not guarantee an equitable distribution of pollution and thus that the introduction of markets could fail to decrease – or actually increase – pollution in some areas (Hernandez-Cortez and Meng 2021).

**Evidence on Environmental Markets and Environmental Justice**

Several studies have investigated how market-based environmental policies affect the distribution of environmental outcomes. For example, Fowlie, Holland, and Mansur (2012) compare the Regional Clean Air Incentives Market (RECLAIM) for nitrogen oxides in Southern California against the counterfactual of a command-and-control policy.[18] They find that RECLAIM substantially decreased $NO_x$ emissions relative to command-and-control and that the decreases in emissions were similar for different demographics.

Grainger and Ruangmas (2018) also study the RECLAIM market but focus on ambient pollution concentrations rather than emissions.[19] They find that examining ambient concentrations rather than emissions leads to somewhat different results and conclude that RECLAIM disproportionately benefitted high-income and white communities.

Hernandez-Cortes and Meng (2021) analyze the impact of California's cap-and-trade market for $CO_2$ on air pollution. They also consider both emissions and ambient concentrations. But rather than focusing on differences across communities by race, they consider a set of "disadvantaged" zip codes

[18] RECLAIM is a cap-and-trade market for nitrogen oxides that began in the Los Angeles region in 1994.
[19] They use a state-of-the-art dispersion model, Hysplit, to translate emissions into ambient concentrations.

(defined by policymakers) and examine how pollution trading affects pollution levels in these versus "advantaged" zip codes. Overall, they find that the market reduces air pollution inequality between advantaged and disadvantaged zip codes.

In another recent study, Shapiro and Walker (2021) analyze a dozen pollution markets in California and Texas. This builds on studies of offset markets, but focuses on 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, offset markets can be used to trace where pollution moves, with existing firms selling the permanent right to emit pollution to entrants. This makes it possible to analyze whether communities where offset markets decrease pollution have different demographics than communities where offset markets increase pollution. In other words, this tests whether offset markets are moving pollution toward or away from low income communities and communities of color. With this in mind, Shapiro and Walker (2021) compare the demographics of communities that sell versus those that buy offsets and find that these communities have similar demographics, thus providing one piece of evidence that these market-based policies do not substantially change the distribution of pollution across communities. More specifically, they find that the share of households that are Black or Hispanic, as well as the share with incomes above the median, are similar for communities where plants sell offsets and communities where plants buy offsets, and that this similarity is consistent across cities, time periods, and pollutants.

**Caveats Concerning Hypothesis 4**

Hypothesis 4 is based on an examination of a few recent studies, which, overall, do not find systematic differences in the distribution of environmental damages between market-based policies and command-and-control policies. Thus, this hypothesis requires stronger caveats than the other hypotheses. This is because the external validity of the estimates in these studies is unknown (i.e., the demographics, market design, pollution dispersion, and other variables may differ substantially between California and other markets). In addition, the four studies discussed above all use somewhat different methods and measures of inequality and Environmental Justice, and present different conclusions, which makes it difficult to generalize the results. That is, although these studies do not find systematic differences between market-based and command-and-control policies, they do not rule out the possibility that such differences exist more broadly.

One clarification concerning the fourth hypothesis is important. The distribution of environmental outcomes refers to the levels of pollution that different people experience. In some settings, it refers to ambient pollution (a purely physical measure), while in others it refers to pollution damages (a more complex metric reflecting demographics and potentially the ability of different households to adapt and protect themselves from pollution). Thus, the distribution of environmental outcomes provides an incomplete measure of the distribution of changes in well-being. 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 increasingly a focus of research and policy.

**Comparison of Efficiency and Equity**

The third and fourth hypotheses permit a comparison of efficiency and equity. In some settings, policymakers face tradeoffs between efficient policies that increase total resources in society or equitable policies that redistribute those resources. The third hypothesis implies that air and drinking water policies have positive net benefits, and thus increase total resources in society. The fourth hypothesis suggests that, at least based on their environmental impacts, market-based versions of these policies do not systematically change the distribution of environmental outcomes relative to less flexible command-and-control policies.

## SUMMARY AND CONCLUSIONS

This article has discussed four hypotheses concerning US pollution and environmental policy over the last 50 years. While my discussion does not provide a comprehensive literature review and focuses only on the US, I find strong evidence for the first hypothesis (air and water pollution but not CO2 are declining), good evidence for the second (environmental policy is causing these trends), emerging evidence for the third (most policies for air and drinking water, but not surface water, pass benefit-cost tests), and only a few tests of the fourth (command-and-control and market-based policies do not have systematically different effects on the distributions of environmental damages).

I have also highlighted recent advances in methods and data that have helped researchers to evaluate these hypotheses. In particular, I have discussed insights from using administrative data on environmental goods, conducting statistical benefit-cost tests, focusing on important but understudied policies, using more sophisticated models of pollution transport, incorporating micro-macro frameworks, and focusing on the distribution of environmental outcomes.

I conclude by highlighting two topics that would benefit from further research. First, I have said little about natural resources like timber, fisheries, or groundwater, and it is unclear whether the hypotheses discussed here also apply to such resources. Thus, further research on this issue would be helpful.

A second issue requiring further research concerns why public and private US groups have managed to decrease "local" air and water pollution but not "global" climate pollution. Textbook economics provides one obvious answer—the climate is a global public good that is subject to a severe free rider problem, while regulating local pollutants provides immediate local benefits. Presumably, other political forces have also contributed to this issue—energy industries influence political decisions, voters have concerns about distributional consequences of climate policy through its impacts on goods and labor markets, and misinformation and inaccurate beliefs shape voters' environmental opinions. Further political economy research is needed to improve our understanding of how to feasibly and efficiently regulate global environmental goods like greenhouse gases.

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