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My research studies two general areas: (1) the interactions of globalization and the environment; and (2) the effectiveness, efficiency, and equity of environmental policy. All this research involves environmental and energy economics, most is empirical, and much has close links to theory. This work uses methods including quantitative general equilibrium models, design-based research, discrete choice and discrete-continuous demand models, sufficient statistics, survey experiments, deep learning, production functions, and integrated assessment models, building on approaches in public and trade, and to a lesser extent industrial organization and health. Several papers introduce large new administrative datasets to research and analyze landmark policies that were not a focus of prior research.

1. Globalization and the Environment

Researchers have long worried that trade could create a "race to the bottom" in environmental policy, leading polluting industries to abandon high-income regions in favor of pollution havens with weak regulation. Additionally, scholars have worried that environmental policy could provide a hidden form of protectionism. I have coauthored two handbook chapters that distill relevant work, one focused on international links (Copeland et al. 2022) and the other on spatial interactions of geography and the environment within a country (Balboni and Shapiro 2024).

Shapiro and Walker (2018) decompose changes in US air pollution across and within manufacturing products, and then build and empirically estimate the first quantitative general equilibrium model of heterogeneous firms with endogenous pollution abatement. Confidential administrative data indicate that most of the time-series US decrease in manufacturing pollution occurs because firms are emitting less pollution to produce a given product, and little occurs because firms are producing different types of products. The model-based analysis finds that the stringency of environmental regulation, measured by the shadow price of air pollution, more than doubled over the period 1990-2008. This change in regulation, rather than changes in trade costs or productivity, accounts for most of the decrease in pollution. Lyubich et al. (2018) provide one motivation for the focus on firm heterogeneity—differences in revenue per ton of CO_2 emitted within narrowly-defined manufacturing industries exceed heterogeneity in labor productivity or total factor productivity. All this work builds on Shapiro (2016), which uses a perfect competition, homogeneous firms, quantitative general equilibrium model of trade and the environment to measure how autarky affects CO_2 emissions and how accounting for CO_2 changes the gains from trade.

Shapiro (2024) instead studies cross-country, cross-sectional patterns of pollution, and finds that financial, judicial, and labor market institutions provide comparative advantage in clean industries. Cross-country differences in the composition of institutions, partly driven by institutions, account for an important share of international differences in environmental quality.

How has trade policy contributed to these patterns? Shapiro (2021) shows the novel stylized fact that in most countries, dirty industries have lower import tariffs and non-tariff barriers than

clean industries. This environmental bias of trade policy provides an implicit subsidy to greenhouse gas emissions, of $85 to $120 per ton of CO_2, and so accelerates climate change. This pattern occurs because dirty industries are systematically upstream, and "tariff escalation" has produced weaker trade protection on upstream goods for at least half a century. Harmonizing trade protection between clean and dirty goods would meaningfully decrease global CO_2 emissions. The European Commission funded an analysis of the potential impact of reforming EU trade policy to follow ideas in this paper, and I testified to the EU Parliament's Trade Policy committee about it.

Trade policies often use non-tariff trade barriers, such as domestic content restrictions or other forms of industrial policy, to pursue global environmental objectives. Allcott et al. (2024) provide the first ex post microeconomic welfare analysis of the electric vehicle subsidies in the US Inflation Reduction Act (IRA), which require assembly in North America for purchased vehicles. This paper uses event study analyses of the roll-out of these subsidies, which provide moments to estimate a discrete choice model of vehicle demand, incorporating leasing. Relative to pre-IRA policy, the electric vehicle subsidies have a marginal value of public funds around 1.8, but they pit trade versus the environment by decreasing carbon emissions even while shifting profits from foreign to domestic manufacturers. The IRA's "leasing loophole," which allows foreign vehicles to bypass trade restrictions if they are leased, decreases US welfare, partly since consumers value a dollar of subsidy for leased vehicles at around 60 cents.

Much research on international economics and the environment focuses on trade. Researchers have long recognized that trade represents only one way that countries interact, but while international economics research has expanded its scope to analyze flows of investment and technology, international environmental economics research largely has not. Garcia-Lembergman et al. (2024) weave together models of multinational production and greenhouse gas emissions to study how policies encouraging multinational production in clean or dirty industries or countries would affect greenhouse gas emissions. One important empirical motivation, later used for parameter calibration, is that firms bring clean or dirty technology with them when they operate abroad—in looking at polluting plants around the world, the home country of a plant's parent firm predicts emission rates just as strongly as the plant's host country does.

2. Effectiveness, Efficiency, and Equity of Environmental and Energy Policy

Commentators in the 1960s worried that US cities would reach unbearable pollution levels by the year 2000. Many types of pollution have instead declined, though greenhouse gas emissions have not. My second research area studies the effectiveness of environmental policy in driving these trends, and the extent to which regulation is efficient and equitable. Shapiro (2022) provides a partial overview.

2.1 Pollution Control Subsidies and Land Use Regulation: Water Pollution Policy

The 1972 US Clean Water Act provides the cornerstone of federal regulation to limit pollution in streams, lakes, and wetlands; the 1974 Safe Drinking Water Act governs federal regulation

of household drinking water. Both laws set ambient environmental standards, provide federal subsidies to pollution control, and restrict land use for environmental reasons. My work studying these policies has involved over 100 Freedom of Information Act requests, data extracted from a decommissioned government mainframe, large national databases compiled from decentralized records, and the first deep learning model of Clean Water Act regulation. This research uses these data to measure national pollution trends, study effects of federal policy on these trends, and estimate willingness to pay for clean water investments. Keiser and Shapiro (2019b) and Keiser et al. (2022) provide overviews.

Since the Clean Water Act, the US has spent over $1.9 trillion to clean up pollution in rivers and lakes, but over half of US stream miles still violate pollution standards. Keiser and Shapiro (2019a) study $650 billion in expenditure due to the Clean Water Act's subsidies to municipal wastewater treatment plants. This work compiles 50 million pollution readings from 240,000 monitoring sites, linked to a network model of 70 million nodes describing the US stream network. The paper finds that river and lake water pollution has declined over the last half century and that the Clean Water Act's pollution control subsidies have contributed to these declines. Effects of these subsidies on nearby home values, however, are less than a fourth of the subsidies' costs. Keiser et al. (2019) highlight that many government and academic analyses also obtain low estimated benefit-cost ratios of investment in surface water quality. Other scholars have taken up the challenge these papers pose of determining whether research is inadequately measuring benefits of water pollution policy or whether its net benefits are negative. Other researchers discuss this work in testimony to the US Congress.

A related challenge appears for US household drinking water, where sources have spent an additional $2 trillion since the Safe Drinking Water Act, but in a typical year 10 to 20 percent of households drink water violating standards. Keiser et al. (2023) construct a national database of 230 million drinking water pollution readings on 1,800 pollutants through Freedom of Information Act requests to US states, linked geographically to administrative Medicare health outcomes. Drinking water pollution is declining rapidly, partly due to investments via the Safe Drinking Water Act, which prevent premature deaths and have large benefit-cost ratios.

Numerous environmental laws restrict land development to protect sensitive water resources, which trade off economic development against environmental protection. The Clean Water Act, a leading example, restricts development on the "Waters of the United States." This legal phrase clearly includes the Mississippi River and excludes backyard puddles, but leaves it ambiguous which isolated wetlands and ephemeral streams are protected; Keiser et al. (2021) describe the legal and economic context. Greenhill et al. (2024) build the first national, geographically-resolved estimate of legally binding Clean Water Act regulation, by training a convolutional neural network to predict 150,000 decisions by the US Army Corps of Engineers. Each Corps decision formalizes Clean Water Act regulation for one water resource. The deep learning model uses 10 terabytes of data on 34 high-resolution geophysical input layers, including aerial imagery, digital elevation models, soil quality, and others. The algorithm indicates that a 2020 White House rule deregulated 21 percent

of all US stream miles, 25 percent of US wetlands, and 30 percent of US drinking water sources. The Biden Administration's economic analysis of its Clean Water Act rule specifically called for this research (text written after meeting with us), and this algorithm is being rolled out to clean energy firms to help them comply with Clean Water Act regulation.

2.2 Environmental Markets and Emission Standards: Air Pollution Regulation

The Clean Air Act uses both environmental markets and command-and-control standards. In part due to this law, ambient concentrations of many air pollutants have fallen by more than 90 percent since 1970. Analysis typically assumes that the marginal cost of abating pollution increases with the quantity of abatement, so given these vast decreases, it is natural to ask at what point regulation becomes more stringent than is optimal.

Environmental economics research has made enormous progress in measuring marginal benefits of pollution regulation in the last few decades, but prevailing methods for measuring marginal costs (i.e., engineering estimates) are largely unchanged. Shapiro and Walker (2024) describe how environmental offset transactions provide a revealed-preference framework to estimate marginal costs of pollution abatement that vary by pollutant, market, and year. In polluted cities, the Clean Air Act requires large new polluting plants to pay incumbent pollution sources in the same metro area to decrease their emissions, so that firm entry does not increase emissions. This research collects data on decentralized bilateral financial transactions from 84 US air pollution offset markets, a large set of environmental markets that prior empirical research had not carefully analyzed. The marginal benefits of pollution abatement exceed estimated marginal costs of pollution abatement more than ten-fold in most markets.

First-best environmental policy is infeasible for the world's 1.4 billion passenger vehicles, since technology cannot measure true on-road emissions. Most countries instead rely heavily on exhaust standards limiting emissions per mile for new gasoline vehicles. Jacobsen et al. (2023) introduce microdata on air pollution emissions covering essentially every model from new US passenger vehicles sold since 1972, and many since 1959. These data are used in difference-in-difference regressions and to calibrate dynamic models of the new and used US vehicle fleets. An analytical model formalizes the "Gruenspecht effect," whereby tightening standards for new polluting durable goods extends the lifetime of used polluting durables and thus may increase total emissions, a phenomenon which has been informally noted for many environmental policies over decades. Air pollution emissions per mile of new US vehicles have fallen spectacularly since regulation began, by over 99%. Exhaust standards caused much of that decline but are cost-ineffective since they largely ignore older used vehicles, which account for a majority of emissions. Differentiated registration fees that accelerate scrap produce $300 billion in present-value welfare gains.

Measuring benefits of environmental policy typically focuses on arguments of the utility function, like mortality or morbidity, but people may invest in costly defenses against externalities. Deschenes et al. (2017) provide the first ex post analysis of how a cap-and-trade market affects ambient pollution and human health using real-world data. Benefits from decreased medication use like

asthma inhalers, which represent one defense against air pollution, nearly exceed an upper bound on the market's abatement costs, though mortality benefits of decreased air pollution still loom large.

2.3 Political Economy and Adaptation

Why have US air and water pollution but not greenhouse gas emissions declined rapidly? While the nature of climate change as a global public good provides one obvious answer, several papers discuss additional hypotheses. One is that Americans can adapt to some costs of climate change. Barreca et al. (2016) find that the effect of extreme heat on mortality fell dramatically after 1960, largely to the roll-out of air conditioning. A discrete-continuous model of electricity demand indicates that the benefits from the prevention of premature mortality due to air conditioning account for a large share of its total consumer surplus. Barreca et al. (2015) similarly find that extreme heat creates smaller mortality burdens in states like Arizona that often experience heat.

Concentrated industry groups provide another explanation for historically weak US climate policies. Many aggregate models of climate change assume complete short-run pass-through of energy price changes to final demand, although industry opposition to climate policy suggests that pass-through may be incomplete. Ganapati et al. (2020) develop a methodology to estimate the incidence of input taxes which accounts for incomplete pass-through, imperfect competition, and substitution among inputs. The approach combines production function estimates, sufficient statistics formulas, and instruments for changes in input prices. The application to several homogeneous US industries finds that 70 percent of short- to medium-run changes in energy input costs are passed through to consumers. Consumers' share of the welfare cost of energy price shocks is 25 to 75 percent smaller than short-run models of perfect competition and complete pass-through would suggest.

Other work tackles another mystery—why do many environmental policies use cost-ineffective policy instruments like standards? Surveys in Lauletta et al. (2024) find that Americans describe impacts on consumer prices as their top priority in choosing among potential environmental policy instruments. Most Americans believe that standards achieve lower consumer prices than market-based policies do to achieve the same environmental outcome, while most environmental economics professors believe the opposite. A survey experiment showing short videos that explain the ideas of allocative efficiency and statutory versus economic incidence results in increased public support for market-based instruments. Limited understanding of these economic principles appears to provide one reason for the prevalence of environmental standards.

These surveys echo others in finding that fairness also drives preferences among environmental policy instruments. Growing political forces oppose environmental markets out of concern that they undermine Environmental Justice and environmental equity objectives. Shapiro and Walker (2021) find that US air pollution offset markets do not meaningfully change spatial patterns of emissions. Relatedly, many observers criticize earmarks (political pork) relative to government subsidies that use formulas for targeting. Keiser et al. (2024) find that while targeting of earmarks

versus federal loans for safe drinking water achieve different demographic targeting, earmarks end up disproportionately targeting Black, Hispanic, and low-income communities, partly because they target water systems serving large and dense populations.

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