RESEARCH ARTICLE SUMMARY

ENVIRONMENTAL POLICY

Plastic bag bans and fees reduce harmful bag litter on shorelines

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INTRODUCTION: Plastic pollution has become a global problem, constituting the majority of marine litter, threatening wildlife, and damaging ecosystems. Among the most common and troublesome categories of marine litter are thin plastic shopping bags, which often evade waste management by floating away in the wind and can entangle or block the digestion of marine animals. Plastic bag bans and fees have emerged as popular policy solutions to address this problem, with >100 countries passing such regulations. Although research has shown that these policies can reduce plastic consumption in some settings, their effectiveness in reducing plastic litter in the environment has not been systematically evaluated. This question is gaining urgency as some US states move to prohibit bag policies, even as 175 countries are in talks to create the first global plastics treaty.

RATIONALE: Whether a plastic bag policy succeeds in reducing shoreline litter depends on how it affects both consumption and waste management. For instance, a partial ban could fail to reduce plastic consumption but still reduce litter if customers substitute thin bags for thicker ones that are less likely to blow away. Or it could reduce consumption but not litter if the bags most likely to become litter are exempted from the ban. To directly measure the impacts of policies on plastic litter in the environment we leveraged the patchwork of hundreds of state and local plastic bag policies that were adopted across the United States between 2017 and 2023. We combined this with crowdsourced citizen-science data from >45,000 shoreline cleanups, in which participants counted and categorized the items they found. Our research design allowed us to control for the share of plastic bag litter in shoreline cleanups before and after each policy's implementation as well as plastic bag litter trends from places that do not have a policy.

RESULTS: Although plastic bags' share of cleanup items increased in general over the study period, it increased by markedly less in areas with bag policies. We find that plastic bag policies lead to a 25 to 47% decrease in plastic bags as a share of total items collected relative to areas without policies. This relative decrease grows in magnitude over time after policy implementation, with no evidence of rebound or spillover effects. Both full plastic bag bans and fees reduce plastic litter, whereas partial bans lead to the smallest and least precise effects, likely owing to exemptions for thicker plastic bags. Policies at all geographic scales are effective, with state-level policies being the most robust. Bag policies yield similar effects along coasts and rivers, with suggestive evidence for larger effects along lakes. They have the greatest impact in places where plastic bag litter is most prevalent. Lastly, we find an imprecise 30 to 37% reduction in the presence of entangled animals in areas with plastic bag policies, although we cannot rule out a null effect.

CONCLUSION: Our findings demonstrate that plastic bag policies have been widely effective in limiting—but not eliminating—shoreline plastic bag debris in areas where it was previously prevalent. If the sample used in our analysis is representative, then expanding plastic bag bans or fees would continue to decrease plastic bag litter and potentially wildlife entanglement compared with business as usual. With waste generation projected to increase, plastic debris entering waters will remain an important global problem in the absence of large-scale policy shifts. □

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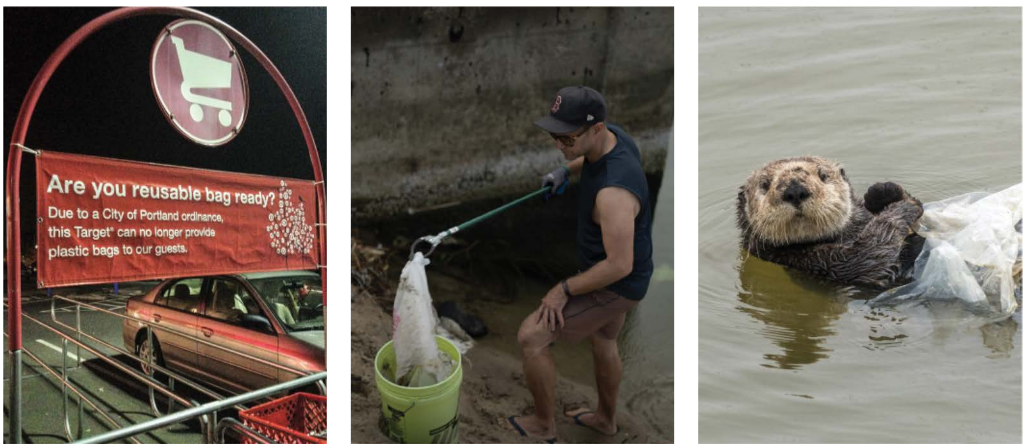

The effects of plastic bag laws on plastic litter in the environment. Plastic debris poses a threat to wildlife and ecosystems. Using data on US policies and cleanups, we show that plastic bag bans and fees limit shoreline plastic bag debris. [Photos (left to right): Tony Webster, 2012, Portland, OR, USA, CC BY 2.0 license; Val Vega, 2023, Los Angeles, CA, USA, courtesy of Ocean Conservancy; Douglas Croft, 2017, Monterey, CA, USA, courtesy of Ocean Conservancy]

ENVIRONMENTAL POLICY

Plastic bag bans and fees reduce harmful bag litter on shorelines

Anna Papp[1]* and Kimberly L. Oremus[2,3,4]*

Plastic pollution threatens marine and freshwater ecosystems and the services they provide. Although plastic bag bans and taxes are increasingly implemented worldwide, their effectiveness in reducing plastic litter remains unknown. Leveraging the patchwork of bag policies across different geographic scales in the United States and citizen science data on 45,067 shoreline cleanups, we assess the impact of these policies on plastic bag litter. We find that plastic bag policies lead to a 25 to 47% decrease in plastic bags as a share of total items collected at cleanups relative to areas without policies, with taxes possibly further reducing shoreline litter. At a time when many jurisdictions are considering bag policies, while others are preemptively prohibiting them, our study provides evidence that they mitigate shoreline plastic pollution.

Plastics have become ubiquitous across the planet, with plastic debris now constituting the majority of marine litter worldwide (*1*–*5*). This widespread pollution poses major threats to marine animals and ecosystems (*6*). Marine plastics may be ingested, leading to fatal digestive system blockages; cause animal entanglement, suffocation, or injury; and release toxic chemicals into the ocean, causing considerable economic and social damages through their adverse effects on various ecosystem services (*7*). Plastic litter on shorelines can also negatively affect tourism and waterfront property values (*8*). According to some estimates, the global social costs associated with damages from plastics to marine natural capital exceed USD 100 billion per year (*9*). Although the literature has focused on marine plastics, recent studies highlight detrimental impacts on freshwater ecosystems as well (*10*). Addressing the problem is becoming a global policy priority: More than 100 countries have national or subnational policies regulating plastic carrier bags (*11*), and 175 countries are in talks to create the first global plastics treaty (*12*).

The vast majority of plastic debris found in the ocean is believed to come from land sources, primarily as a result of waste mismanagement. Most mismanaged plastic waste reaches the oceans through rivers, but plastic can also arrive via wastewater discharge and wind or tidal transport (*13*, *14*). Previous studies have modeled the fate of plastics and the flow of the material from land to the ocean (*15*–*17*). Approximately 2 to 5% of generated plastic waste worldwide is estimated to enter the oceans annually, with local variation driven by population size and quality of waste management (*16*). A global survey of 12 million marine litter items found that plastic bags were the most common, accounting for 14% of all items (*18*).

Single-use plastic shopping bags are common objects with notoriously low recycling rates that are easily caught and transported by winds. Both command-and-control approaches (such as outright plastic bag bans) and economic incentives (such as fees or taxes on bags) are growing in popularity around the world. These include a variety of state and local bag policies in the United States, which is estimated to be the 20th-largest direct contributor to marine debris (*16*). Bag policy proponents often cite the effects of plastics on aquatic ecosystems (e.g., animal entanglement) as reasons to regulate single-use plastic materials. However, there has been only anecdotal evidence that plastic bag policies may be reducing plastic litter (*19*).

Observational studies using point-of-sale scanner data find that select local US plastic bag policies decrease disposable, thin plastic bag consumption at grocery checkouts (*20*–*22*). However, the same studies find a substitution toward consumption of paper, reusable bags, and thicker plastic bags, especially in the case of narrowly defined bans (e.g., bans that only prohibit thin plastic bags) (*20*, *22*). For this reason, fees (taxes) on bags appear to be more effective in reducing total bag consumption. Internationally, evidence on the effectiveness of bag fees is mixed. Whereas policies in England, Scotland, Wales, and Buenos Aires have led to reductions in bag use (*23*, *24*), and policies in Taiwan have decreased waste and recycling (*25*), South Africa's bag fee resulted in only temporary declines in plastic bag consumption (*26*).

What these studies have not answered is how these effects on plastic bag consumption translate to the policies' underlying goal of reducing plastic litter, particularly in shoreline and aquatic environments. This depends on how the policies affect both consumption and waste management. For example, a plastic bag policy could fail to reduce plastic consumption because of substitution with thicker bags [in the case of a partial ban (*20*)] or unregulated bags, such as restaurant takeout bags or purchased garbage bags (*27*). Yet a plastic bag policy could still reduce plastic bag litter in the environment if it turns out the substituted bags are more likely to be reused or recycled, less likely to fly away in the wind, or less likely to disrupt waste management by jamming recycling machines (*28*). Only a few pathways illustrating how plastic policies influence the movement of plastic bags, from consumption through waste management to environmental litter, are documented in the literature (fig. S1). Reports and papers with summary statistics of plastic litter before and after bag policy implementation do not control for litter trends over time and are often looking at the effects of a single policy with small sample sizes (*19*).

Literature has highlighted the need to more systematically evaluate whether plastic bag policies are positively affecting the marine environment (*29*). This research gap is becoming increasingly important as 175 countries attempt to negotiate the first international treaty on plastics, following a commitment in 2022 at the United Nations Environment Assembly (*12*). The question has also come up in legislative analyses of US state-level bills that would prohibit local regulation of plastic bags (*30*), known as "preemption" laws. As of September 2024, 17 US states have passed full preemption laws that prohibit their counties and towns from regulating plastic bags.

We fill this knowledge gap by leveraging data on tens of thousands of shoreline cleanups and hundreds of local policies to provide causal evidence on market-based and command-and-control policies' roles in reducing plastic litter in the environment. We first compile data on 611 town-, county-, and state-level plastic bag policies and categorize them according to policy characteristics. This allows us to estimate descriptive statistics on the reach of plastic bag policies. We then use crowdsourced data on 45,067 shoreline cleanups from January 2016 to December 2023 to circumvent the usual challenges of measuring plastic pollution. Although shoreline cleanups do not capture all aquatic litter, they offer a proxy for the prevalence of various litter types, including plastic bags. There were 182 policies implemented from January 2017 to December 2023, a period we selected to begin 1 year after our cleanup data for control purposes (see materials section in the supplementary materials for more details on the data collection and cleaning). We leverage the rollout of plastic bag policies across the US and implement various difference-in-differences estimators robust to heterogeneous treatment effects (*31*–*34*) to identify the causal effects of plastic bag policies on plastic litter in the environment. These estimators allow us to control for the share of plastic bag litter prior

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to a policy as well as plastic bag litter trends from places that do not have a policy.

We first present the overall effect of plastic bag policies on plastic litter in the environment on the basis of evidence from shoreline cleanups. Our analysis shows that plastic bag policies result in a 25 to 47% reduction in the proportion of plastic bags among the total items collected during cleanups compared with places without policies. We then explore heterogeneities by the policy type (full ban, partial ban, or fee), geographic scope of the policy (state, county, or town), type of shoreline (coast, river, or lake), and baseline concentration of plastic bags. Finally, we examine whether bag policies reduce wildlife entanglement.

Patchwork of US plastic bag policies

Plastic bag laws in the United States vary widely, making it a useful laboratory for comparing the effects of different policies. Policies have been implemented at the state, county, and town levels. We define town policies as anything at a geographic scale smaller than a county, including cities and townships. Common types of policies include bag bans, bag fees, and preemption laws. Bag bans are command-and-control policies prohibiting certain retailers from distributing plastic bags. Bans may be complete or partial, the latter prohibiting only thin, disposable bags. An example of a complete ban is New York's March 2020 statewide ban, and an example of a partial ban is Washington's October 2021 statewide ban. The latter allows the distribution of plastic bags at least 2.25 mm thick made from at least 40% recycled materials. These thicker plastic bags are often considered "reusable" under partial ban policies, although there is evidence that some consumers still treat them as single-use (*35*). Bag fee policies (or taxes) require stores to collect a small fee (usually ranging from 5 to 25 cents) on each disposable plastic bag the consumer takes. An example is the 5-cent tax on disposable plastic shopping bags in Arlington County, Virginia. Finally, 17 states have passed full preemption laws that prohibit jurisdictions within that state from passing bag policies, often as a way of ensuring that plastic bags will remain unregulated. Another two states have partial preemption (prohibiting either only bans or fees), and one state (Pennsylvania) had a temporary preemption.

We document 611 total policies from 2008 through 2023 addressing plastic bag pollution across the country (summarized according to the geographic scope and type of policy in Fig. 1A and in table S1 and by geographic coverage in fig. S2). Ten states have implemented state laws, and 43 counties have passed county-level bag legislation, but most policies (558, or 91%) are at the town level. Plastic bag fees are the least common type of policy, although most policies passed after 2021 are either fees or full bans, as partial bans have fallen out of favor.

Matching policies with affected zip codes enables us to provide estimates of the number of Americans who live in areas with plastic bag laws, broken down by geographic scope and type of policy (Fig. 1B). As of December 2023, about one in three Americans, or 116 million in all, lived in a jurisdiction with a bag law. Since the recent increase in statewide policies, state-level policies cover the largest number of Americans (90.7 million, or 78.2% of those living in areas with bag policies), followed by town- and county-level policies (10.0 million, or 8.6%, and 15.3 million, or 13.2%, respectively) (Fig. 1B).

Plastic bags are prevalent in shoreline litter

The Ocean Conservancy provides citizen science data from shoreline cleanups, where volunteers pick up and categorize litter from a stretch of coast, river, or lake (*36*). Our analysis includes 45,067 shoreline cleanups from January 2016 to December 2023 (fig. S3). Plastic bags are the fifth-most-common item found in US shoreline cleanups (after cigarette butts, food wrappers, plastic bottle caps, and plastic beverage bottles), out of a total of 60 distinct item categories (fig. S4). On average, plastic bags make up 4.5% of the items collected in a cleanup, however, this number rose to 6.7% in 2023 (fig. S5). Although plastic bags in shoreline cleanups represent an unknown fraction of all plastic bag litter, the cleanup data offer a plausible proxy for the overall reduction in marine and freshwater plastic litter that the policies achieve. It is for this reason that we focus on the percentage reduction in plastic bags as a share of cleaned-up litter rather than on the absolute number of plastic bags reduced by the policies. We aggregate the cleanup data to the 0.1° grid cell (or ~11.1 km), as 98.6% of our cleanups cover this much distance or less. We also aggregate the data by zip code to match the geographic scale of our policy data. Temporally, the data are aggregated by year to match the annual peak in the histogram of time between cleanups (fig. S6 shows that the histogram is right-skewed with a long right tail), while giving us enough observations to create a balanced panel from January 2016 to December 2023. We estimate that 65.6% of the cleanups are within 10 km of the coast and that 86.6% of the cleanups are in watersheds that drain into the oceans.

There were 182 plastic bag policies in zip codes that had shoreline cleanups, affecting a cumulative 15 million Americans (Fig. 1, C and D, and table S2). These 182 policies were used to generate the main results.

Bag laws reduce plastic bag prevalence on shorelines

We find a 25 to 47% decrease in plastic bag share in treated areas compared with places without policies (Fig. 2A and table S3). This range reflects the range in point estimates from five different estimators [two-way fixed effects (TWFE) and estimators described in (*31*–*34*)] using eq. S1 (see materials and methods in the supplementary materials). This decrease is normalized to the control mean (4.5% of items collected). While plastic bag share increased overall in both treated and untreated areas, it increased by considerably less in the treated areas. We present our main results using our preferred aggregation level (0.1° or ~11.1 km grid cell by year) as well as a zip-code-by-year aggregation (Fig. 2, A and C). The results using the 0.1° grid-cell-by-year aggregation are statistically significant at the 5% level for all estimators. The results at the zip-code-by-year aggregation are statistically significant for four of the five estimators and somewhat less precise for one (*32*), likely owing to additional noise created by aggregating to a larger geographical unit.

Next, we investigate the dynamic effects of plastic bag policies, using an event-study-style plot of treatment effects by year (eq. S2), where the first year is the first full year for which a policy is in effect (Fig. 2B and fig. S7A). This approach also allows us to check for pretrends. We do not see evidence of pretrends (1 to 3 years before laws were implemented), but we do observe decreases in plastic bags' share of total items relative to untreated areas in the years after the implementation of a policy (years 1 to 5). The magnitude of the relative decrease grows over time, and we do not find evidence of rebound effects, at least within the first five years of a policy. We repeat these analyses for a subset of grid cells for which we are able to construct a balanced panel. Because cleanups take place sporadically, constructing a balanced panel drastically reduces the number of observations available for our analysis. For this reason, we use an unbalanced sample in our primary analysis. However, both the overall and dynamic effects are similar using a balanced panel subset of the data (Fig. 2, C and D, and fig. S7B).

We then conduct falsification (placebo) tests on plastic litter items whose prevalence we do not expect to change in response to plastic bag laws. We look at the share of plastic bottles and caps, plastic straws, and plastic containers and do not find decreases in the share of these plastic items after bag policies are passed (fig. S8). This reassures us that the decline in the share of plastic bags relative to untreated areas is driven by the policies rather than by general decreases in plastic usage or litter that happened to coincide with the policies. A slight increase in the share of these nonbag plastic items may be mechanical: As the share of plastic bags decreases, the share of other commonly collected items may increase. We also run our analysis on

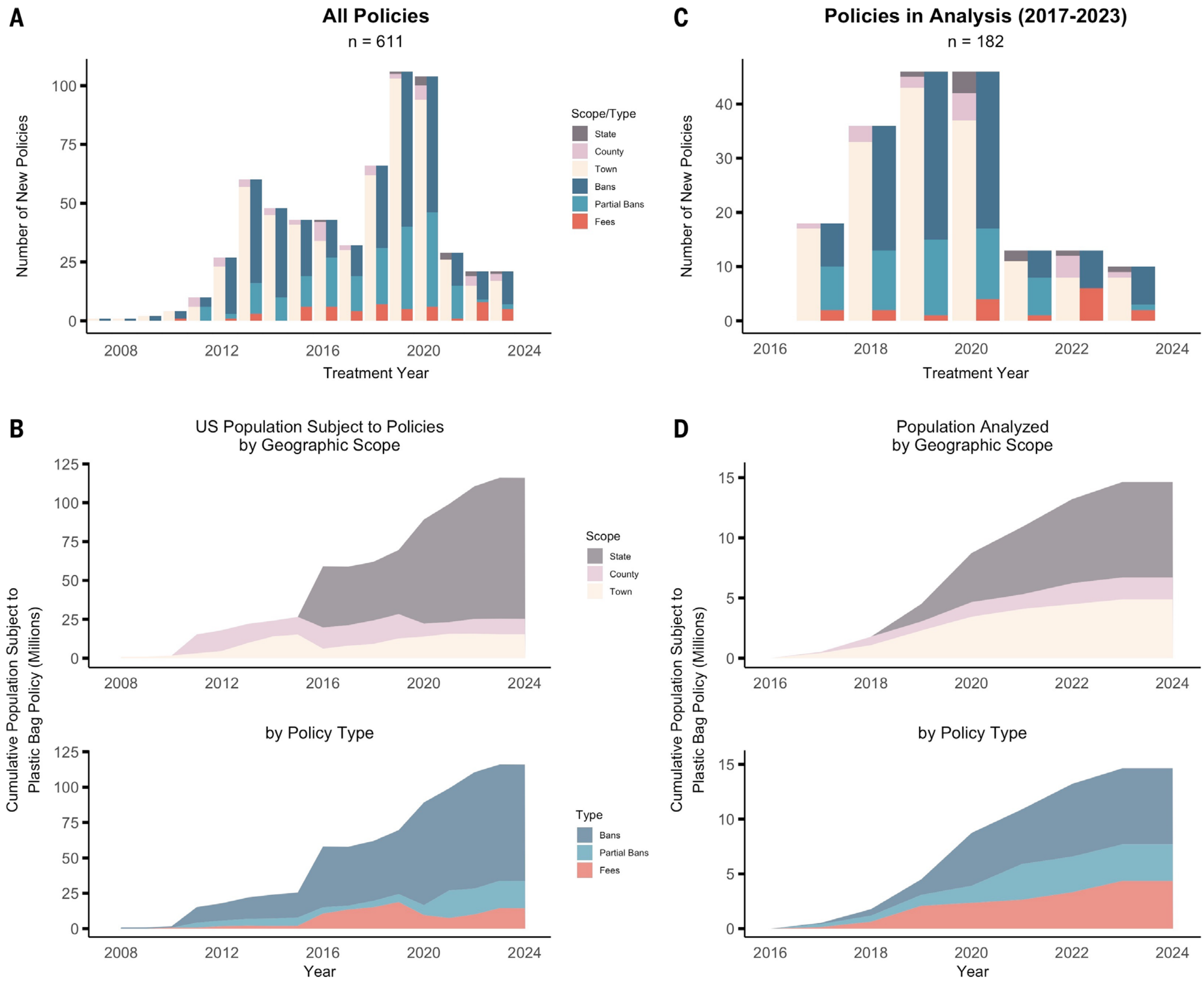

Fig. 1. Summary statistics on US plastic bag legislation. (**A**) The number of new policies implemented in each year (2008–2023) by geographical scope and type of policy. [Four policies before 2008 are not shown. These are town-level bag bans in Nantucket, MA (1990); Galena, AK (1998); Saint Paul Island, AK (2002); and San Francisco, CA (2007).] (**B**) The cumulative number of US residents in a locality with plastic bag laws of various geographical scope (top) and policy type (bottom). If a zip code experiences different policies over time, the first type of policy is shown. (**C**) The number of new policies implemented in each year that are used in our analyses (2017–2023). This is determined both by policy timing and cleanup locations. (**D**) The cumulative number of US residents in zip codes with policies and cleanups used in our analyses, shown by geographical scope (top) and policy type (bottom). If a zip code experiences different policies over time, the first type of policy is shown.

the number of all cleanup items to ensure that these results are not driven by changes in the denominator (fig. S9). We do not find evidence of bag laws affecting the total number of items collected. We also repeat our analyses for a subset of cleanups more consistent in size or timing (coastal cleanups and annual International Coastal Cleanup Day cleanups) using the number of plastic bags collected per person. We find decreases in this measure as well (fig. S10).

Next, we implement several alternative specifications to test the robustness of our main results. In these main analyses, we assume that the outcome variable is unbounded. However, in reality, plastic bags' share of cleanup items is between 0 and 100%. We repeat our analyses using a beta regression and logit transformations of the dependent variable and show that this assumption does not meaningfully affect our results (fig. S11). We also repeat our main analyses with only plastic "grocery" bags and find similar although slightly less precise results, likely because of inconsistent classification between plastic grocery bags and other plastic bags. We also test different levels of temporal and spatial aggregation of the cleanup data. In addition to aggregating cleanup observations at the year level, we aggregate at the quarter and month levels. We also test spatial aggregation at the 0.01° (or ~1.1 km) grid cell level. We find that our main results hold across all these spatiotemporal scales, although, as expected, our estimates are less precise when aggregating at too small a scale (e.g., 0.01° cell by quarter). In our main analysis, we use the date the first policy took effect in a given zip code. In robustness checks, we repeat our analysis only with areas with exactly one policy and separately restrict our analysis only to treated areas. We then also restrict the cleanup data to only large cleanups (>25 attendees), small cleanups (<5 attendees), and those without kids. We also address concerns that COVID-19–related changes in plastic litter may coincide with plastic bag law implementation (e.g., areas with stricter plastic waste policies may also have stricter pandemic measures). To account for this, we rerun our regressions, excluding observations first from 2020 and then from both 2020 and 2021. Overall, our main results are robust to these alternative samples and approaches (fig. S12). Finally, repeated cleanups in the same area are a cause for potential concern as prior cleanups—not

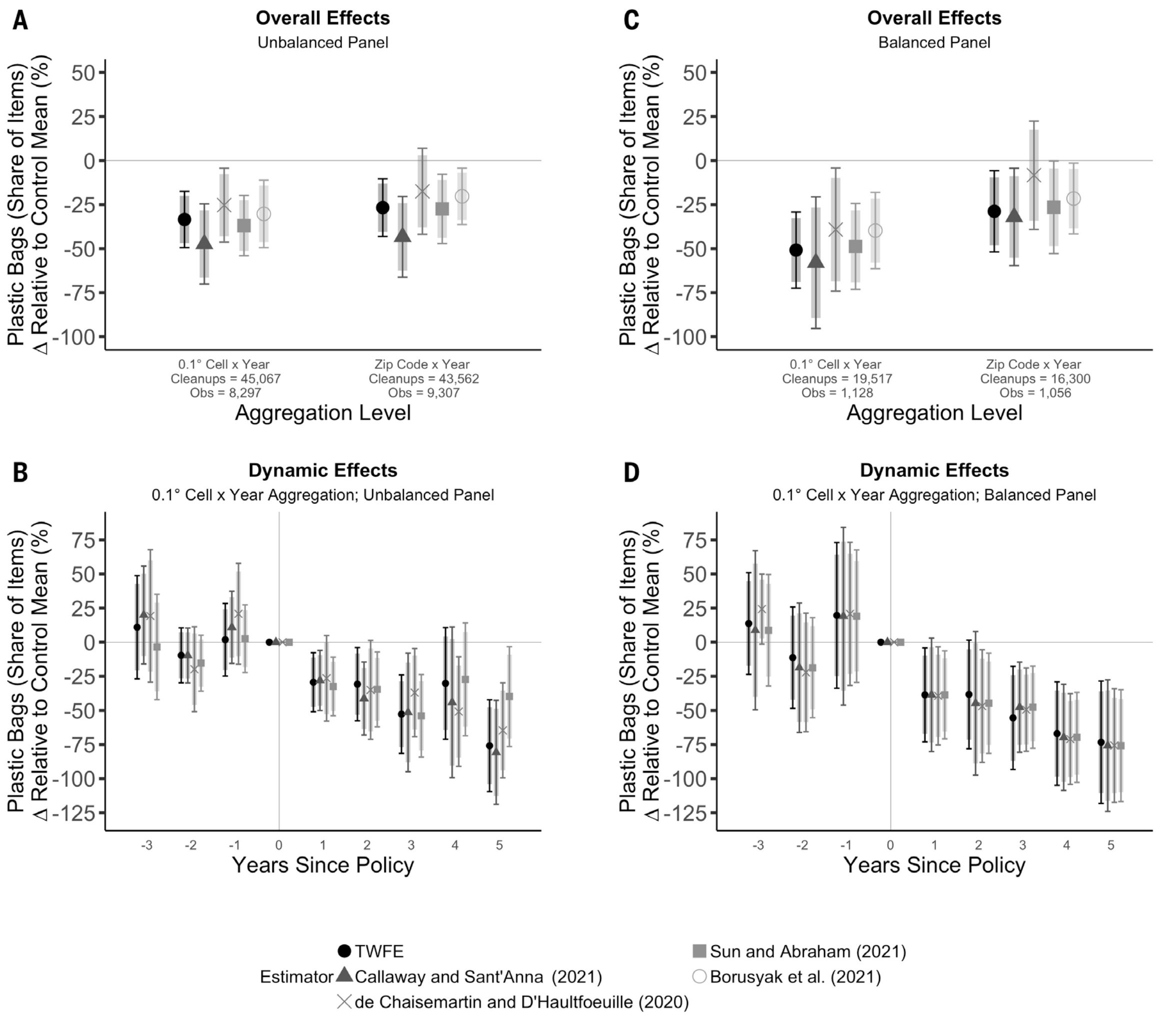

Fig. 2. The effects of bag policies on plastic litter. Coefficient plots for regressions using five estimators [TWFE and (*31*–*34*)]. The outcome variables are plastic bags' share of total items collected during shoreline cleanups as documented in the TIDES data. Results are divided by the control mean (4.5%). We use 2016–2023 (inclusive) cleanup data and examine the effects of 182 bag policies implemented beginning in 2017. Obs, observations. (**A**) Overall (after versus before) effects for the entire (unbalanced) sample, according to eq. S1, for various spatiotemporal aggregations. (**B**) Dynamic effects for the 0.1° grid cell by year aggregation level, according to eq. S2. We do not show results using (*34*) on the same plot, as suggested by (*46*) (fig. S7). Year 1 is the first full year for which a policy is in effect. (**C** and **D**) Results in (A) and (B), respectively, but for a balanced panel subset. In all panels, in the event of multiple policies in a unit, the effective date of the first policy is used (see fig. S12 for robustness to alternative approaches). Zip codes with repealed policies and all their neighbors, including those two or three zip codes away, as well as all neighbors of treated zip codes, are excluded from the main analysis. Thick lines show a 90% confidence interval, and thin lines show a 95% confidence interval. Standard errors are clustered by zip code.

policy changes—may lead to lower item counts or bags being removed at different rates than other litter. As a robustness check, we run our regression controlling for the number of cleanups (fig. S12). We also conduct an analysis comparing the time passed since the last cleanup in the same 0.1° grid cell and differences in cleanup characteristics. We find that with every additional day between successive cleanups, the change in share of items that are plastic bags is very small compared with the mean (table S4).

Spillover analysis

Next, we examine whether there are spatial spillovers or transboundary movements of plastic litter associated with plastic bag policies. These spillovers could be negative or positive. If people living in treated areas try to avoid the ban by increasing shopping and littering in untreated neighboring areas, then we would be overestimating the policy's true effect. Alternatively, there could be beneficial spillovers if stores in treated areas serve people from untreated areas or if stores near treated areas implement their own bag policies. In these cases, we would be underestimating the policy's true effect. Testing for spillovers, we do not find statistically significant effects in neighboring zip codes. Imprecisely, we find potential beneficial spillovers on the zip codes immediately neighboring treated areas but possible negative spillovers two zip codes away from the treated area (i.e., neighbors of neighbors) (Fig. 3B). Out of an abundance of caution, in our main specification (Fig. 2), we drop the neighbors, neighbors of neighbors, and neighbors of neighbors of neighbors (i.e., three zip codes away) of zip codes with bag policies (see Fig. 3A for an illustration of zip code treatment categories in North and South Carolina).

Heterogeneity by policy type, scope, and location

We test the effectiveness of various types of policies in reducing plastic litter. We first explore the differences between complete bans, partial bans, and fees (taxes). While we find relative decreases in plastic litter for both bans and fees, we find the magnitude of the decrease to be

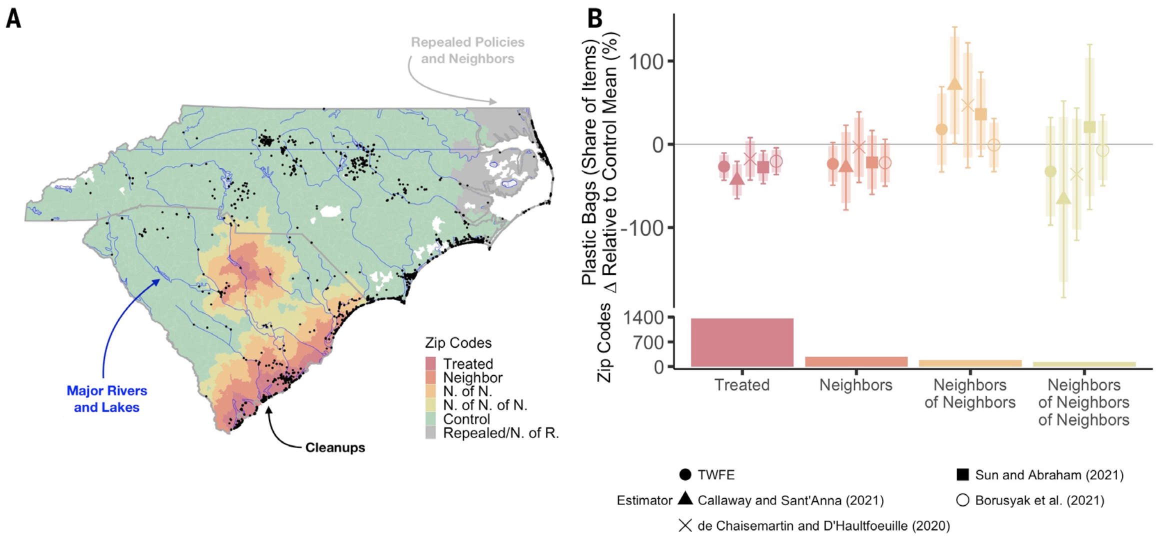

Fig. 3. Spillover analysis. (**A**) South and North Carolina zip codes are used to illustrate the spillover definitions. The zip codes' colors represent treatment category: treated zip codes with bag policies, zip codes neighboring these policies, neighbors of neighbors (N. of N.), neighbors of neighbors of neighbors (N. of N. of N.), and control zip codes. Zip codes whose policies were repealed and their neighbors, neighbors of neighbors, and neighbors of neighbors of neighbors are all in gray. (**B**) Panel shows the effect of bag policies on plastic bag litter across these treatment groups, for all of the United States. Regression outcomes are according to eq. S1 using five estimators [TWFE and (*31*–*34*)] and using the zip code by year aggregation level. Zip codes with repealed policies (and all neighbors) are dropped from the analysis. The outcome variables are plastic bags' share of total items collected on shoreline cleanups documented in TIDES, divided by the control mean. Thick lines show a 90% confidence interval, and thin lines show a 95% confidence interval. Standard errors are clustered by zip code.

much larger for fee-based policies (Fig. 4A). As there are fewer policies with fees, our estimates of the effect of these policies have larger confidence intervals, so the differences in the magnitude of effects between these policies are only suggestive. It is also worth noting that several of the fee-based policies are in landlocked zip codes whose shorelines are along rivers and lakes (fig. S2). Partial bans show the smallest and least precise effects, perhaps owing to exceptions for thicker plastic bags.

We then study the effects of policies at different geographic scales and separate state, county, and town-level policies. We find that all geographic scales of policy are effective, with state-level policies being the most robust (Fig. 4B). In general, we observe relative declines in plastic litter across most of the eight coastal states that have implemented bag policies between 2017 and 2023 (fig. S13).

We also explore effects across different types of water bodies. Whereas bag policies had similar effects along coasts and rivers, there is suggestive evidence that they had larger effects along lakes (Fig. 4C). This may be due to the fact that litter along lake shorelines is less likely to spill over into neighboring areas than is litter along coasts and rivers (see "Spillover analysis"). While these estimates are larger in magnitude, they are also noisier because of the smaller sample size. Additionally, we break out results by connection and proximity to oceans, including results for cleanups within 10 km of coasts and those in watersheds that drain to oceans (fig. S14). Finally, we explore whether bag policies have larger effects on places with more litter before policy enactment (fig. S15) and find that they do. In fact, most of our results are driven by places that had higher shares of plastic bag litter before the policy (Fig. 4D). These are areas where plastic bags make up 13.2% of items collected, on average, and are in the 75th percentile or above in share of plastic bag litter. Bag policies appear to show no effect on areas that already had low shares of plastic bag litter. However, we cannot disentangle whether this is because consumer behavior did not change as a result of the policy, these areas have better waste management, or these areas have land cleanups before litter reaches shorelines.

Effects on wildlife entanglement

Although plastic bags make up a small percentage of shoreline litter at any point in time, plastic's long life cycle allows it to accumulate in the ocean over time. The coastal cleanup data provide counts of entangled animals found along the shoreline. We find an imprecise 30 to 37% reduction in the presence of entangled animals due to plastic bag policies in comparison to places without policies, using an unbalanced panel of data on entanglements (Fig. 5A). These estimates are noisy because plastic bags are not the only cause of animal entanglement. How plastic bags, other shoreline litter, and wildlife interact is not well understood. Results are larger and statistically significant for some but not all estimators using a balanced panel (Fig. 5B). We find an imprecise reduction in entanglements using a conditional logit model (table S5) and using the number of entangled animals as an outcome variable (fig. S16). This result suggests that plastic bag policies may be reducing animal entanglement, but we cannot rule out the possibility of a null effect. Further data and research are needed to confirm these findings and understand the broader ecological impacts on aquatic ecosystems.

Discussion

Our findings make clear that plastic bag policies have been broadly effective in limiting—but not eliminating—shoreline plastic bag debris in jurisdictions where it was previously prevalent. There is also suggestive evidence that fees may have a greater impact than bans, especially partial bans, although further research is needed to understand why. If we assume that the sample used in our analysis is representative of all plastic bag litter in the US aquatic environment, then increasing the prevalence of plastic bag bans or fees would continue to decrease plastic bag litter and potentially wildlife entanglement compared with business as usual. The external validity of these results, including outside the US, would depend on how different consumption and waste management are from our sample. For example, parts of Africa are estimated to have 12 times more uncollected or mismanaged plastic waste than the United States (*13*). This suggests that the impact

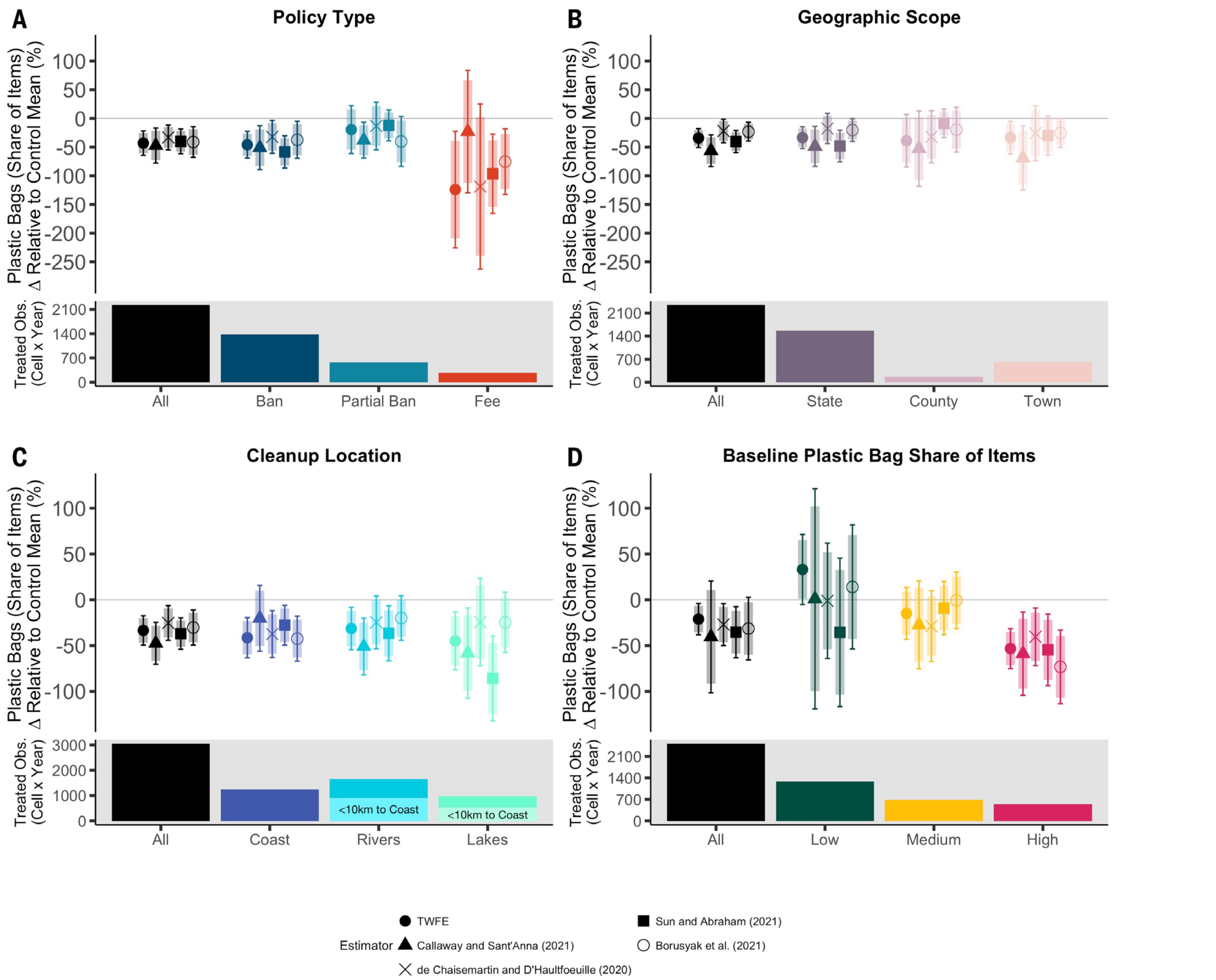

Fig. 4. Heterogeneity. Regression outcomes according to eq. S1 using five estimators [TWFE and (*31*–*34*)]. The outcome variables are plastic bags' share of total items collected, divided by the control means. (**A**) Heterogeneity by type of policy, including treated areas and control areas. Only treated grid cells with exactly one type of policy during 2017–2023 are included. (**B**) Heterogeneity by geographic scope of policy, including treated areas and control areas. Only treated grid cells with exactly one geographic scope of policy during 2017–2023 are included. (**C**) Heterogeneity by cleanup location type: coastal, river, and lake. All cleanups are within 1 km of each type of shoreline and include treated and control areas. Only 1.1% of analyzed cleanups are not within 1 km of a water body (not shown), otherwise all treated and control areas are included. Furthermore, 42.0% of river and 34.7% of lake cleanups analyzed are within 10 km of the coast. (**D**) Heterogeneity by the baseline (before policy) average of plastic bags as a share of all cleanup items collected. Only treated grid cells areas are included (not controls). Low baseline areas have pretreatment levels of plastic bags' shares below the median (<2.9%), medium areas are between the median and 75th percentile (2.9 to 5.6%), whereas high areas are above the 75th percentile (>5.6%). Control means are calculated as pretreatment averages (and are 2.7, 5.2, and 13.2%, for low, medium, and high baseline areas, respectively). In all panels, thick lines show 90% confidence interval, and thin lines show 95% confidence interval. Standard errors clustered by zip code.

of plastic bag policies could be even greater in many jurisdictions outside the US, although that impact could be blunted if the policies are not well enforced.

While plastic bags present distinctive problems for waste management and animal life, the data on US shoreline cleanups suggest that regulating other single-use plastic items, such as plastic water bottles and caps (the third- and fourth-largest categories of shoreline litter, respectively), might further reduce plastic litter in the environment. However, it is important to note that different categories of plastic may have different mechanisms of supply, consumption, and waste management, so policies regulating them may yield different results. This highlights the potential importance of policies on plastic production, such as the global treaty on plastics that countries aim to continue negotiating in August 2025 (*37*). As waste generation is projected to increase through the end of the century (*38*), the leakage of plastic debris into the world's oceans will remain an important problem in future decades in the absence of large-scale policy shifts.

Materials and methods summary

In this study, we combine two main sources of data. First, we collect all US state-, county-, and town-level plastic bag regulations from various sources (*39*–*45*). For each, we record the effective date and policy type and match to covered zip codes. We download data on US shoreline cleanups from TIDES [Trash Information and Data for Education and Solutions (*36*)]. The main variable of interest we derive is plastic bags as a percentage of the total items collected in a cleanup. We then match cleanups to zip codes and determine treatment status. For our main analysis, we aggregate cleanups to the 0.1° latitude/longitude (or ~11.1 km) grid cell by year level on the basis of the characteristics of the cleanup data. We consider a grid cell

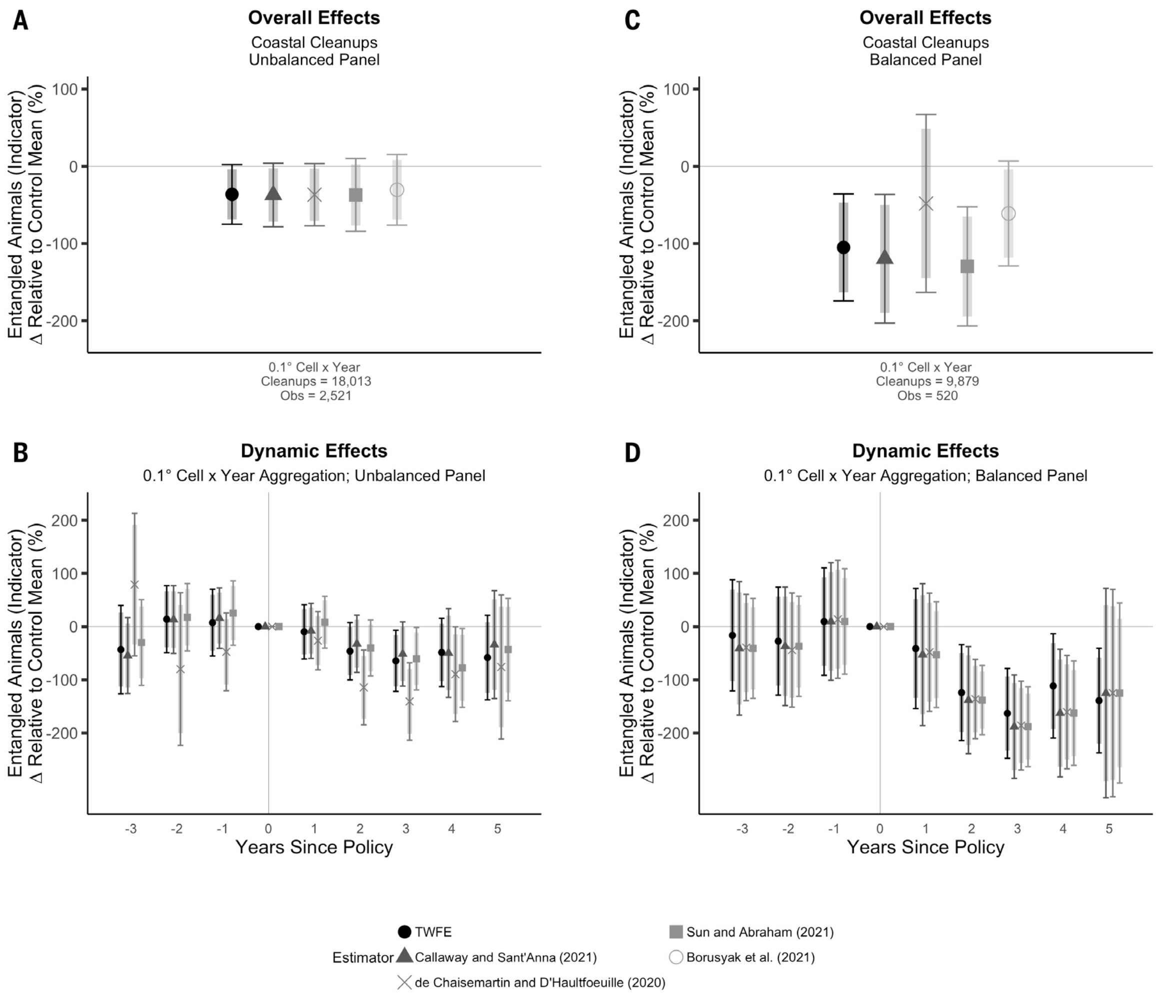

Fig. 5. Entangled animals. The effect of plastic bag policies on entangled animals found during coastal cleanups estimated according to eq. S1 using five estimators [TWFE and (*31*–*34*)]. The outcome variable is an indicator dummy variable that is set to 1 if there are entangled animals (injured or dead) found during cleanups in the relevant 0.1° grid cell and year. We repeat our analysis using a conditional logit model (table S5) and using the number of entangled animals as an outcome variable (fig. S16). Entanglement in materials other than plastic bags is excluded (although material is noted only for 7.1% of entanglement events). Data were retained for entangled animals with missing entries for entanglement debris. (**A**) Overall effects for the entire (unbalanced) sample, according to eq. S1. (**B**) Dynamic effects for the 0.1° grid cell by year aggregation level, according to eq. S2. (**C** and **D**) Results in (A) and (B), respectively, but for a balanced panel subset. In all panels, thick lines show 90% confidence interval, and thin lines show 95% confidence interval. Standard errors clustered by zip code.

treated if it is located inside a zip code that is treated. If there are multiple zip codes in a grid cell, then we use the zip code first treated for the purposes of our analyses. The 45,067 cleanups used in our main analyses are limited to 2016–2023 (data before 2016 is sparse) and exclude areas with existing or repealed policies as well as spillover areas.

We use a straightforward difference-in-differences empirical strategy that leverages the rollout of plastic bag policies across the United States. The simplest empirical model we use is a two-way fixed effects regression, where we regress the outcome of interest from the cleanup data on a treatment indicator dummy and unit (grid cell) and year fixed effects that control for time of year and local characteristics (eq. S1). To study the dynamics of treatment effects as well as to test for parallel trends, we also estimate an event-study version (eq. S2). In addition to this estimator, we also use heterogeneity-robust TWFE estimators proposed by (*31*–*34*). For more details on both materials and methods, see the full materials and methods section in the supplementary materials.

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SUPPLEMENTARY MATERIALS

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Materials and Methods; Figs. S1 to S16; Tables S1 to S5; References (*48*–*51*)

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