Environmental Pollution and Authoritarian Politics

Carlo M. Horz, Texas A&M University
Moritz Marbach, University College London
Christoph V. Steinert, University of Mannheim

Authoritarian rulers fend off revolutions by stimulating the economy. However, expanding the economy can also increase environmental pollution. If citizens value clean air and water, worsening pollution has the potential to galvanize large segments of the society against the regime—which increases the risk of a revolution. While the literature has documented how concerns over the environment upend politics in democracies, we know relatively little about the effects of these concerns in authoritarian regimes. We analyze environmental pollution as an overlooked threat to authoritarian rulers. Using unique data from Communist East Germany and exploiting variation in thermal inversions to instrument for pollution levels, we find that pollution causes both individual and collective expressions of regime dissatisfaction. Our findings suggest that rulers face a trade-off between growing the economy and worsening pollution.

In October 1989, several thousand citizens of the German Democratic Republic (GDR) protested in the city of Leipzig to demand economic and political reforms. To scholars of authoritarian politics, citizens protesting and demanding economic improvements is a familiar sight. Indeed, current research shows that economic concerns are a crucial determinant for antiregime protests. Specifically, if there is a substantial decline or stagnation in citizens' economic fortunes, citizens might rebel to oust the ruler from power (Acemoglu and Robinson 2006; Chassang and Padró i Miquel 2009; Fearon 2011). However, the protesters in Leipzig also displayed a number of signs whose messages feature less prominently in the literature on authoritarian politics. The protesters wanted to "saw down the kleptocrats, not the trees" and demanded "Leipzig air, without sulfuric odor" (quoted in Bölsche et al. 1989, 92). Thus, they signaled grievances about environmental pollution. Journalists from West Germany observed that after decades of environmental pollution and state-orchestrated repression of the environmental movement, members of the latter seemed poised to bring down the regime (e.g., Wensierski 2014).

In theory, the idea that concerns about the environment can mobilize citizens seems natural. After all, pollution reduces air and water quality and hence indirectly causes or aggravates asthma, lung diseases, skin conditions, and allergies and weakens people's heart and cardiovascular system. Health professionals from the Lancet Commission have found that "diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide—three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence" (Landrigan et al. 2018, 462). As a result of these enormous health consequences, it is intuitive that pollution can have serious political repercussions. Consistent with this view, a growing literature has documented how concerns about the environment upend politics in democratic polities, especially in Europe: from the mobilization of grassroots organizations to the founding—and eventual rise to power—of green parties (Dryzek et al. 2003; Müller-Rommel and Poguntke 2002).

However, there are relatively few empirical analyses that directly study the effect of pollution in authoritarian regimes. Does environmental pollution affect the politics of authoritarian regimes? We first discuss the effects of pollution theoretically, distinguishing between a direct and an indirect effect.

Carlo M. Horz (carlo.horz@tamu.edu) is an assistant professor in the Department of Political Science, Texas A&M University, College Station, TX, USA. Moritz Marbach (m.marbach@ucl.ac.uk) is an associate professor at the University College London, United Kingdom. Christoph V. Steinert (christoph.steinert@gess.uni-mannheim.de) is a postdoctoral researcher at the University of Mannheim, Germany. Authorship is alphabetically listed.

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Given pollution's adverse health consequences detailed above, citizens might directly experience a loss in utility and hence feel compelled to punish officeholders when experiencing pollution—especially when they are not compensated by high levels of economic performance. Moreover, pollution may indirectly matter by informing citizens about a lack of policy-making competence of the regime. This is the case even though pollution is part of a complex attribution problem to citizens in a sense that observing pollution does not guarantee that the regime is incompetent. However, with increasing government involvement in the economy, for example, citizens' ability to learn about the regime's competence also increases. Both the direct and the indirect effects of pollution suggest that an increase in pollution causes an increase in citizens' antiregime behavior.

We then scrutinize empirically the relationship between pollution and citizens' attitudes and actions toward the regime using data from the GDR. We combine satellite data measuring changes in pollution levels with data on citizens' individual and collective expression of regime opposition. To measure collective expressions of discontent, we analyze data on the protests in 1989 that led to the downfall of the regime. To measure individual expressions of regime discontent, we rely on complaint letters that aggrieved citizens sent to officials. In total, our data cover the political events in the last decade of the GDR.

Identifying the effect of pollution on citizens' expressions of discontent is challenging. As indicated above, economic performance will likely affect pollution as well as citizens' attitudes, which makes it a confounder. Moreover, simply controlling for economic performance is arduous since accurate measures are difficult to obtain in authoritarian regimes (Hollyer, Rosendorff, and Vreeland 2011). To address this challenge, we implement an identification strategy pioneered in economics: instrumenting pollution using thermal inversion (e.g., Arceo, Hanna, and Oliva 2016; Chen, Oliva, and Zhang 2017; Jans, Johansson, and Nilsson 2018). A thermal inversion is a reversal in the temperature gradient in the lower atmosphere because of weather changes. Thermal inversions are well known to reduce the diffusion of polluting particles in a local area and therefore increase pollution levels near the surface. We provide evidence that these thermal inversions are exogenous to citizens' expressions of discontent with the regime in our empirical case.

In contrast to evidence from US elections (Bergquist and Warshaw 2020) but consistent with work on the effect of pollution on protesting in China (Deng and Yang 2013), we find that environmental pollution affects outcomes in authoritarian politics. Our main result is that pollution mobilized protesters in larger numbers during the regime-ending protests in 1989. Protest participation in 1989/90 increased by about 5% relative to the average number of protesters per protest event in places that had a 1 standard deviation weaker decline in pollution (as measured by sulfur dioxide, SO_2) throughout the 1980s. We complement and bolster this finding in two ways: first, we show that pollution mobilizes citizens to protest earlier in the protest cycle; that is, in counties with a 1 standard deviation weaker decline in SO_2 during the 1980s, the likelihood for mobilization in the first 90 days of the protests increased by 13 percentage points. Second, focusing on an individual expression of discontent, we demonstrate that pollution increases the volume of complaint letters. We find that an increase of about 1 standard deviation in SO_2 increases the number of letters that focus on environmental pollution by about 12% relative to the sample mean. Overall, our empirical results demonstrate how pollution affects citizens' attitudes toward the regime, fuels overall antiregime sentiments, and mobilizes a vanguard for regime change. By measuring citizens' discontent using both complaint letters and protests, our analysis offers a degree of robustness that is not achieved by a single measure of discontent.

Our findings have important implications for theories of authoritarian politics and the literature on authoritarian politics more generally (e.g., Svolik 2012). First, our results suggest that not only is there an economic performance constraint operating in autocracies (i.e., autocratic rulers need to provide some economic opportunities to citizens), but there is also an environmental pollution constraint (i.e., rulers cannot increase pollution by too much since they otherwise face rebellion). The existence of this additional constraint implies a potential trade-off for rulers: if citizens value both a clean environment and economic performance, but economic performance increases pollution, autocratic policy making will have to strike a balance between these goals. Second, previous work points to horizontal inequalities (Cederman, Weidmann, and Gleditsch 2011), economic policies (Thomson 2018), or repression (Bell and Murdie 2018) as drivers of grievances. We complement this line of work by identifying environmental pollution as an important and previously underappreciated determinant of antiregime grievances.

Third, writing a complaint letter and protesting are both expressions of discontent, yet they have different implications for regime stability. In particular, for an autocratic regime, protests are clearly more threatening than receiving letters.[1] Similar to mechanisms in other authoritarian regimes, the GDR's letter-based complaint system was designed to gather information about citizens' attitudes and to manage discontent before it escalates into large-scale protests (Botero, Ponce, and Shleifer 2013; Chen and Xu 2017). Our results therefore speak to

1. Mass protests are the most frequent cause of authoritarian regime breakdowns since 1990 (Svolik 2012).

evidence on the efficacy of autocratic attempts to measure discontent via information-gathering institutions (Chen and Xu 2017; Lorentzen 2013). In order to make such institutions effective, citizens need to participate and be willing to reveal their private information truthfully. But citizens may refuse to do so if they fear negative repercussions for speaking out truthfully, rendering the mechanism ineffective. Theoretical work suggests that the GDR's letter-based institution is conducive to eliciting citizens' opinions (Spaniel and Ding 2018); we corroborate this theoretical account by showing that letter writing was extensively used by East German citizens and that topics shifted in systematic ways in response to changing circumstances. Our results demonstrate that setting up an information-gathering institution can work, but it is no guarantee for avoiding regime-changing protests.

Empirically, our article demonstrates that pollution has consequences not only for politics in democracies but also in authoritarian regimes. The existing literature in environmental politics has largely focused on advanced democracies, highlighting how electoral politics shapes environmental outcomes (e.g., Burgess et al. 2012) and vice versa (e.g., Bergquist and Warshaw 2020; Müller-Rommel 1989). However, there is little work on how pollution shapes authoritarian politics. The exception is qualitative evidence (e.g., Deng and Yang 2013) demonstrating a link between (small-scale) mobilization in rural China and pollution. The quantitative study by Alkon and Wang (2018) shows that pollution levels in Beijing shape attitudes toward the regime, but it remains silent on the consequences for citizens' political behavior. The lack of evidence is surprising especially in the light of country-level studies demonstrating that regime type matters for pollution outcomes (Congleton 1992; Fredriksson and Wollscheid 2007; Li and Reuveny 2006; Ward, Cao, and Mukherjee 2014).

Our study also contributes to the understanding of the contentious politics in the final decade of the GDR (e.g., Crabtree, Darmofal, and Kern 2015; Horz and Marbach 2022; Kern and Hainmueller 2009). Qualitative evidence from both journalists and historians suggests that environmental concerns contributed to the formation of dissident networks in the former GDR (Huff 2015) and to the regime-ending protests in 1989. In this article, we provide quantitative evidence substantiating the link between pollution, mobilization, and the collapse of the communist East German regime.

HOW POLLUTION MATTERS FOR CITIZENS' DECISION-MAKING

Preferences over economic performance and pollution

Since it is difficult to remain in power without a minimum of public support, authoritarian leaders have to manage citizens' level of discontent. While the literature has provided a range of explanatory factors for regime discontent, including corruption or poor public services, many theories of authoritarian politics focus on economic variables as central factors shaping citizens' attitudes and thus outcomes in autocracies. For example, modernization theory predicts that economic development causes democratization because increasingly rich citizens demand democracy (Lipset 1959). Acemoglu and Robinson (2006) assume that economic shocks lower citizens' opportunity costs of protesting, and so democratization is caused by the threat of protests following instances of economic downturns (see also Chassang and Padró i Miquel 2009). Boix (2003) focuses on asset mobility to explain variation in authoritarian rule, arguing that less mobile capital impedes democratization. Broadly speaking, these theories assume that citizens care about their economic well-being and will consider protesting when their economic fortunes decline or stagnate (Fearon 2011). As a result, autocrats must—at least to some extent—implement policies that improve citizens' economic well-being, which represents a fundamental constraint on their rule.

An important issue that has received limited attention in the literature is that under many reasonable production technologies, improvements in economic performance worsen environmental pollution. Consider figure 1*A*, where economic performance (and therefore income) and pollution are positively linked: the higher the economic performance, the higher the level of pollution.[2] Specifically, figure 1*A* illustrates output possibilities in the economic performance-pollution space when the relationship between these two variables is monotone and linear.[3] The exact relationship depends on the nature of the current technology, which is denoted by θ. A more advanced technology implies that the increase in pollution that is caused by an increase in economic performance is lower. In the figure, the technology $\bar{\theta}$ is more advanced than the technology $\underline{\theta}$.

To investigate how citizens evaluate both economic performance and pollution, consider figure 1*B*, which illustrates a representative citizen's preferences via several indifference

2. For clarity, we display a deterministic relationship between economic performances and pollution. In reality, the relationship is stochastic—a fact that we exploit in our empirical analysis.

3. The exact relationship between economic performance and pollution is subject to an ongoing debate. While the positive relationship between those variables is intuitive and has received some empirical support (e.g., Cole, Rayner, and Bates 1997), others have argued that it should be nonmonotone. The environmental Kuznets curve hypothesizes that when economic performance is sufficiently high, an increase in performance has a negative effect on pollution, because economic growth gives the means to combat pollution. Note, however, that this nonmonotonicity is presumably induced by change in technology, whereas our conceptualization keeps technology fixed.

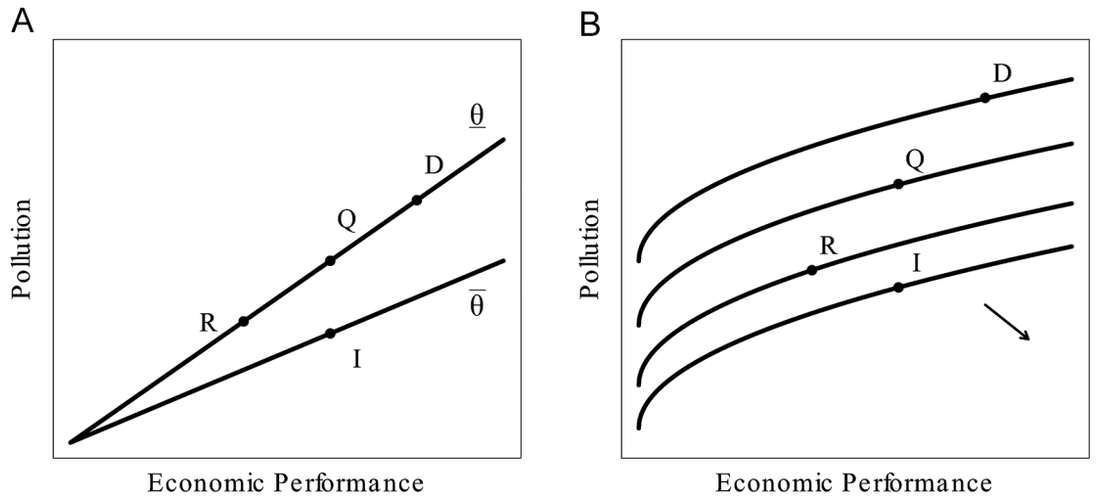

Figure 1. *A*, Policy outcomes. Relationship between economic performance and pollution for two different technologies. A higher level of economic performance implies a higher level of pollution, but the increase in pollution that is associated with an increase in performance is lower when the technology is more advanced ($\bar{\theta}$ instead of $\underline{\theta}$). *B*, Citizen's indifference curves for four levels of utility as a function of economic performance-pollution output pairs. Indifference curves that are shifted toward the bottom-right corner imply a higher level of utility.

curves. Clearly, the citizen should approve of high economic performance (it is a "good") but disapprove of pollution (it is a "bad") because of its effect on the citizen's health. Consequently, an indifference curve is upward sloping—an increase in pollution must be compensated by an increase in economic performance. Figure 1*B* displays several indifference curves and the citizen attains a higher level of utility when indifference curves are shifted to the bottom-right corner.

Suppose that the status quo policy mix yields the point Q and that citizens are relatively dissatisfied with this output pair because of unacceptable levels of pollution. The regime has three salient options for improving the citizen's satisfaction: it could reduce pollution via an investment in technology, so that outputs change from Q to I (investment); it could reduce pollution via a reduction in economic performance while keeping the existing technology, inducing a change from Q to R (reduction); or it could "double down" by increasing both pollution and economic output using the existing technology, inducing a change from Q to D (double down).[4] In figure 1, both the investment decision from point Q to point I and the reduction policy from Q to R make the citizen better off, while the move from point Q to point D reduces the citizen's utility.[5]

The previous discussion highlights that pollution could directly affect citizens' utility. Similar to moral hazard models in electoral accountability (e.g., Fearon 2011) or "grievance"-related arguments in civil war theories (e.g., Collier and Hoeffler 2004), pollution then causes antiregime behavior because citizens wish to punish current officeholders for lowering their utility. However, pollution might also matter indirectly by changing citizens' beliefs, a possibility that we discuss next.

Pollution: Observability, attribution, and regime competence

Environmental pollution is the result of a complex causal process that poses significant challenges to citizens' attempting to learn about their government's responsibility—and its ability to deal with the problem. The following causal chain is a useful stylized representation of this process:

$$\text{Government type/policy} \rightarrow \text{Emission of polluting substances} \rightarrow \text{Intermediate effects} \rightarrow \text{Environmental degradation.} \quad (1)$$

For example, the government may decide not to implement any regulation that leads to the emission of phosphor. This polluting substance is causing acid rain and forest dieback and increasing carbon dioxide emissions, which contribute to

4. We abstract away from the possibility that, due to, e.g., depreciation of technology, there could be a "depression case" in which pollution goes up but economic output decreases.

5. This does not have to be the case; for some utility functions, a change from Q to D increases the citizen's utility. This is because we have only assumed that the citizen's utility is monotone in both pollution and economic performance, so decreasing or increasing both can increase or decrease utility. Then, an increase in pollution might be associated with a decrease in protesting (unless pollution also informs about policy-making competence, and this latter effect is stronger).

environmental degradation in the form of rising global temperatures and more wildfires.[6]

To begin with, at least some of the variables in the causal process have to be observable—otherwise citizens cannot use them to update their beliefs about relevant attributes of the regime. Often, emissions are directly observable, and harmful attributes can at least be conjectured.[7] For example, dark smoke from industrial plant chimneys can be observed, and it is difficult to hide even in regimes that use censorship. Other times, however, only the effects of emissions can be observed, and citizens need to acquire additional (perhaps scientific) information about the causes of the effects.[8] Worse still, effects might be delayed, only occur under certain conditions, or have cumulative effects that are dependent on certain tipping points. For example, lakes can develop "dead zones" that occur only if oxygen reaches a critically low concentration level.

If citizens can observe pollution, they can learn about an underlying state of the world that they care about. Existing research suggests that the government's policy-making competence is a crucial driver for citizens' political support decisions (Ashworth 2012). If more competent rulers are better at preventing pollution, citizens should negatively update understanding about the regime's competence when observing high levels of pollution.[9] As a consequence, citizens might protest in order to replace the regime with a new one.[10]

When is the complex attribution problem outlined in expression (1) more or less manageable? First, the effectiveness of the regime's propaganda and censorship may matter. In the GDR, the regime attempted to censor any news about pollution and often blamed bad environmental pollution on neighboring West Germany, noting, for example, that industrial plants close to the border failed to meet environmental protection standards.[11] More generally, the experiences of other countries may be important for citizens' attempts to learn about pollution's causes and correlates. Existing research suggests that citizens benchmark when evaluating their leader's economic performance (Kayser and Peress 2012). Similarly, citizens may take into account other countries' environmental problems when deciding how big of a problem theirs is. Other countries' media landscape may also be freer than the one in the citizens' home polity. When access to this information is available across borders (e.g., via personal communication in cross-border networks or because of cross-border media availability), citizens may be able to use extra information to learn more about the causes of pollution.

Second, citizens' inferences may be more powerful if citizens can observe both emissions and their effects locally. If that is the case, correlations about the cause (pollution) and the effect (environmental degradation) can be directly formed—and governments held accountable. By contrast, if the polluting substance and environmental outcome are only distantly related (either temporarily or spatially, such as in the case of climate change), citizens' learning process is more challenging.

Third, an important factor is the state's involvement in the economy. In socialist economics such as in the GDR, the state plays a dominant role through ownership and tight regulation. Except for the black market, the market is the state. By contrast, in laissez-faire economies, the state is virtually absent. As a consequence, the first arrow in the causal chain displayed above is much stronger in the former case than in the latter, and citizens can be more certain about the regime's role in causing pollution. These are important scope conditions of our argument.

From pollution to political action

Since pollution has adverse effects on citizens' welfare and potentially deteriorates citizens' trust in the policy-making competence of the regime, it is likely that at least some citizens take action. Even in nondemocratic societies, citizens have several options through which they can express dissatisfaction with the regime. Analytically, one can distinguish between actions that are more individual versus those that have a collective action component. The existing literature has analyzed complaints, sabotages, assassinations, strikes, and protests (e.g., Scartascini and Tommasi 2012). Writing a complaint letter or engaging in economic sabotage are actions whose net benefit does not depend on the number of other individuals that take it. By contrast, strikes and protests have a clear collective action

6. Clearly, the representation in expression (1) omits several important factors, e.g., private actors. It is an analytical simplification to guide our discussion.

7. For some emissions, whether they are harmful is also uncertain. For simplicity, and to focus on the attribution of government responsibility, we abstract away from this possibility.

8. A relevant distinction is between an event (forest fire, flooding) and a (more gradual) process (forest dieback, acidification). Events are more visible but are more random than processes.

9. There is qualitative evidence that citizens in the GDR lowered their assessment of policy-making competence when observing pollution (see Wensierski 1986).

10. Apart from policy-making competence, an important consideration is the regime's competence at employing repression. In some cases, policy-making and employing-repression competence may be positively correlated; i.e., there is a general competence to "get things done." In this case, observing pollution suggests that the regime is neither good at fixing pollution nor able to employ repression—in which case citizens' incentives to protest are strengthened. For simplicity, however, we assume that pollution only informs citizens' of the regime's competence at policy making, which is in line with qualitative evidence from our empirical case.

11. See the regime's primary propaganda newspaper, *Neues Deutschland*, December 7, 1987, p. 5.

component in the sense that the relative benefit from engaging in the action depends on the number of other citizens taking the action. In either case, we expect there to be a positive effect of pollution on antiregime behavior.

In the preceding discussion, we abstracted away from the perception and behavior of the regime. As discussed above, when observing or anticipating citizens' actions, autocratic leaders can attempt to change their economic policies in order to reduce these expressions of grievances. But they can also employ repression in order to quell discontent. Given this ever-present possibility of violence (Svolik 2012), citizens must take into account the expected behavior of the regime unless they act purely expressively. Given the threat of repression, when will citizens have an incentive to express their discontent?

In the appendix, we present a game-theoretic model of the strategic interaction between a citizen and an authoritarian regime.[12] In this game, citizens might rebel against a regime that they believe to be incompetent. We assume that pollution provides a noisy but informative signal about the regime's competence, but only some citizens care significantly about pollution, relative to other issues. When citizens observe high levels of pollution, these citizens must ask themselves whether it is worth their while expressing their discontent by writing to the regime that they consider pollution to be a serious problem. Citizens face a trade-off: the regime may fix the issue (if doing so has relatively low costs), but their letter may also prompt the regime to employ repression and thereby reduce the likelihood of protesting that is motivated by high levels of pollution. Analyzing the equilibrium of this game, we find that citizens will send a complaint letter if they are sufficiently confident that the regime is responsive. Citizens may turn to protesting even after sending a letter if they do not see sufficient improvements. Our model therefore demonstrates that citizens have incentives to express their discontent even when facing the threat of repression, as long as some of them initially believe the regime to be responsive.

The theoretical discussion demonstrates that there is ample reason to expect that pollution matters for outcomes in authoritarian politics. Rulers cannot tolerate too much pollution since they otherwise face rebellion. We next substantiate this theoretical argument by providing evidence that pollution prompts both individual and collective expressions of discontent by citizens.

12. We also discuss to what extent our analysis is robust to modeling multiple citizens and incorporating complementarities at the letter-writing stage. Specifically, there could be a "no participation" equilibrium in which there is no information transmission to the regime; i.e., citizens do not write letters because they (correctly) do not expect other citizens to do so. In this case, we focus on the equilibrium with a positive probability of writing a letter, which approximates our current analysis.

EMPIRICAL ANALYSIS

Our empirical analysis focuses on the last decade of the GDR, from 1980 to just before the regime collapsed in 1989. The GDR is an important and useful case to examine the political effects of pollution, as it used to be Europe's most notorious environmental polluter and the regime struggled with severe environmental degradation in the 1970s and 1980s (Möller 2019; Thüsing 2013). Moreover, focusing on the GDR enables us to measure both collective expressions of discontent (protesting) and individual expressions of discontent in the form of citizens' complaint letters (*Eingaben*). It is often difficult to measure individual expressions of discontent in authoritarian regimes since they are less public by nature. The GDR represents a unique context to study both individual and collective expression of discontent.

To measure pollution reliably, we use satellite data from NASA (see Barwick et al. [2019] and Chen et al. [2017] for a similar measurement strategy). The MERRA-2 data set provides global estimates of the amount of SO_2 on a monthly basis since 1980 for grid cells of about 50 × 50 km (Gelaro et al. 2017).[13] We focus on SO_2 in the main analysis but also discuss the results for dust immissions ($PM_{2.5}$) for which MERRA-2 also provides estimates. We aggregate these grid-cell estimates for each year and map them to the county level, as all other data that we are using are observed on this level.[14]

Figure 2*A* illustrates the variation in SO_2 levels in the data. Sulfur dioxide is a bad-smelling gas that is typically emitted from the burning of fossil fuels in, for example, power plants and other industrial facilities. In combination with other pollutants, it reduces visibility and has several adverse health effects, especially for the respiratory system. Moreover, in combination with other pollutants, SO_2 contributes to the formation of acid rain, which is an important cause of deforestation (Greaver et al. 2012; Lippmann 2020).

Our main analysis focuses on how changes in pollution affected protest mobilization in 1989. We compute this change by regressing time (measured in years) on SO_2 levels for each county separately. The coefficient measures the average change in SO_2 between 1980 and 1988. Our data suggest that, on average, immission levels were falling throughout the 1980s (on average about 1 kg/m^3 every year). However, this decrease occurred faster in some counties and slower in others.

Our protest data come from the Citizens Movement Archive Leipzig, which maintains a database of protest events

13. See app. sec. A.3 for the data version we are using and the data repository source.

14. A county estimate is calculated by taking the weighted average of the grid cells covering a county. The weights are proportional to the area of a grid cell covering a county.

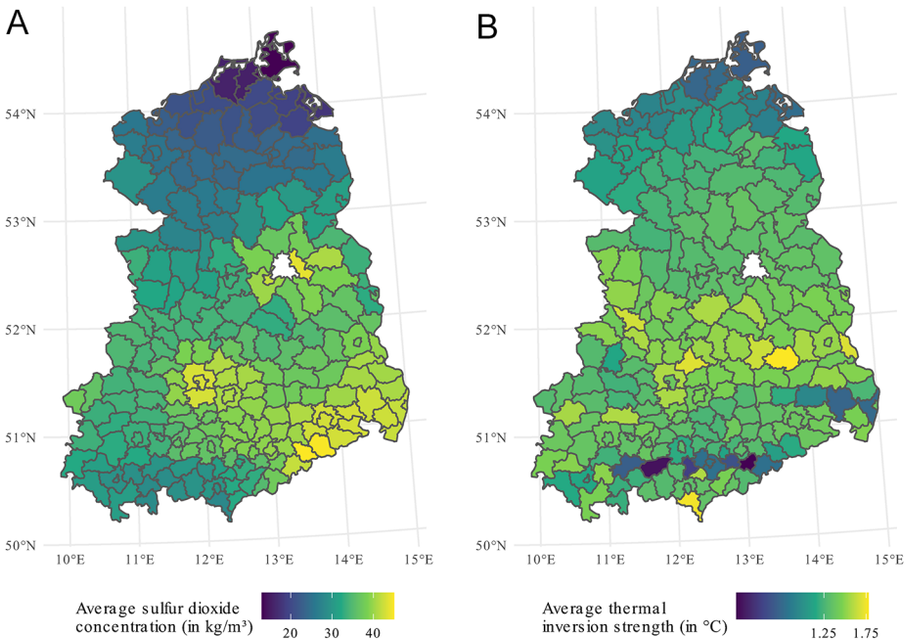

Figure 2. (*A*) Average sulfur dioxide concentration (in kg/m³) and (*B*) average thermal inversion strength (in °C), 1980–89

that occurred between 1989 and 1990.[15] This database includes 3,212 protest events that occurred between August 13, 1989, and April 30, 1990. For our main analysis, we use these data to measure the number of protesters per capita across protest events. We standardize protest participation counts with the population size in a county (per 10,000) as of 1989 and use the logarithm of this variable as our dependent variable.

In our baseline ordinary least squares (OLS) specification, we regress protest participation (y_i) on changes in SO_2 levels between 1980 and 1989 ($\Delta SO2_i$) and a set of control variables (X_i):

$$y_i = \alpha + \beta \Delta SO2_i + \gamma X_i + \varepsilon_i. \quad (2)$$

We use clustered standard errors at the county level and exclude the county of Berlin.

Most of the variation in air pollution is due to differences in the local economy. More specifically, places with industrial production plants have higher levels and larger changes of air pollution than places without industrial production plants. Hence, regressing protest activity on pollution is unlikely to identify a causal effect. We address this concern by instrumenting pollution using thermal inversions in a two-stage least squares regression (2SLS).

Instrumenting pollution with thermal inversions

Previous research suggests that thermal inversions are highly predictive of pollution (e.g., Arceo et al. 2016; Chen et al. 2017; Jans et al. 2018). Usually, air temperature decreases with an increase in altitude. A thermal inversion is a temporary atmospheric phenomenon in which this relationship is reversed, and the temperature increases with altitude. One consequence of such inversions is that pollution particles are trapped closer to the ground. As a result, pollution levels are higher. Thermal inversions have many different causes, but in many instances they are caused by a warmer air mass moving over a cooler air mass (e.g., Finardi, Carboni, and Tinarelli 2002; Iacobellis et al. 2009).

We follow the previous literature and exploit the occurrence of thermal inversions as an instrumental variable to identify the effect of air pollution. The instrumental variable uses variation in air pollution immissions due to atmospheric temperature differences to estimate the effect of air pollution on citizens' expression of discontent. This variation, as we demonstrate below using a series of falsification tests, is not correlated with important confounders such as the presence of industry in a county.

To construct the instrumental variable, we follow previous work and use the MERRA-2 data set, which includes information on air temperature at 42 altitudes measured in six-hour intervals. We use the average of the largest thermal inversion at any day during the year as the instrumental variable. An inversion is any positive difference between the temperature measured at the lowest altitude and the second-lowest altitude. Figure 2*B* illustrates the cross-sectional variation in the instrumental variable. Details on the construction of the instrument can be found in appendix B, where we also

15. See https://www.archiv-buergerbewegung.de/themen-sammlung/demonstrationen. See app. sec. A.2 for more details on these data.

demonstrate the high correlation with other versions of the instrumental variable used in the literature (lowest vs. third-lowest altitude, lowest vs. fourth-lowest altitude).

The identifying assumption of our instrumental variable research design is that thermal inversions affect citizens' expression of discontent only through their effect on pollution levels. Previous work has argued that this identifying assumption is credible after controlling for ground weather by adding annual average temperature and precipitation levels as control variables to the regression. To further increase the credibility, we add fixed effects for counties that had the same SO_2 emission levels in 1982. This means that we effectively only compare counties that had the same expected level of SO_2 immissions but differed in the realized level because of, among other things, thermal inversions. Data on emissions are extracted from maps prepared by the former East German Ministry for Environmental Protection and Water Management, which we collected in the German federal archive.[16] These maps do not report immissions but (estimated) emission levels (in six groups) based on the output of a county's industry.[17]

To probe the credibility of our identifying assumption, we report the results of 26 falsification tests in which we replace the SO_2 immissions in the first-stage regression with measures of county-level attributes taken from Crabtree et al. (2015).[18] If the instrument is exogenous, we should expect to see no correlation between these (potential) confounders and the instrument beyond what is to be expected by chance alone. As shown in figure C.1, we only find a significant correlation ($p \leq .05$) for two measures: distance to Berlin and average housing space. Given a significance level of .05, we note that these two positive tests could be due to chance alone. However, and more importantly, we find no correlation between other measures of population concentration, geography, the local economic structure, and the intensity of the June 1953 protests. We therefore conclude that these falsification tests increase the credibility of our identifying assumption.

Pollution and protest participation

Table 1 displays the OLS estimates (models 1–3) and the 2SLS estimates (models 4–6). The first-stage estimates are displayed in table C.4. We find that OLS tends to underestimate the effects. In the most demanding specification, we instrument the change in pollution and include covariates as well as fixed effects. We find that a 1 standard deviation smaller decline in pollution increases the number of protest participants by about 7% relative to the average number of protesters.[19]

Table 1. Effect of Change in SO_2 Immissions on Number of Protesters

	OLS			IV		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
ΔSO_2	.68*	.92**	.96**	1.30*	1.87*	2.26**
	(.27)	(.32)	(.30)	(.57)	(.76)	(.83)
Covariates	No	Yes	Yes	No	Yes	Yes
Emission groups FE	No	No	Yes	No	No	Yes
F (instrument)				17.03	16.94	16.25

Note. The effect of change in SO_2 immissions between 1980 and 1988 (kg/m^3) on the number of protesters (per 10,000 capita) across 3,212 protests between August 1989 and April 1990. Covariates: annual change in temperature and precipitation, 1980–88. Instrument: average thermal inversion strength (1980–88). Standard errors in parentheses. $N = 3{,}104$. OLS = ordinary least squares; IV = instrumental variable; FE = fixed effects.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

In the appendix, we demonstrate that alternative definitions of the instrument tend to reduce the first stage but do not substantially change the pattern of the estimates (tables C.5 and C.6). We also show that the point estimates are robust to (i) adjusting for five temperature and precipitation bins rather than the continuous covariates (table C.7); (ii) adding the two covariates, which we found to be correlated with the instrument in the falsification tests (table C.8); and (iii) estimating a version of the 2SLS model that includes a spatially lagged dependent variable and a spatially lagged error term following the advice of Betz, Cook, and Hollenbach (2020; table C.10).[20] We note that some of the estimates fail to reach the .05 significance level. However, encouragingly, in these instances it is not because the coefficient estimates shrinks but rather because the standard errors increase.

16. The archival sources are described in app. sec. A.4.

17. In general, emissions describe the output of a pollutant at the source, while immissions measure the concentration of pollutants in the environment.

18. We use the covariates listed in table 1 of their article. We only exclude measures of environmental pollution and measures that could be affected by pollution (number of exit visas and change in population size).

19. We multiply the coefficient by the standard deviation of the independent variable and scale by the sample mean of the dependent variable; i.e., $(2.26 \times 0.17)/5.14$.

20. We thank an anonymous reviewer for this suggestion.

Finally, in additional analyses reported in the appendix, we find a similar pattern when it comes to dust immissions (table C.11). In the appendix, we also report the results when we regress the protest participation counts on the average level of SO_2 immissions between 1980 and 1988 (table C.9). The results suggest that only the change in pollution in the decade before the protests but not the level of pollution increased the number of protesters per capita. This seems consistent with the idea that only noticeable changes in the environment affect citizens' behavior.

Overall our results suggest that pollution mobilized the masses in 1989. However, one concern with the analysis might be that the robust first-stage (Kleibergen-Paap) statistic is relatively small ($F = 16.25$). While this F-statistic is still sufficiently strong relative to commonly used rules of thumb regarding the strength of an instrument (Stock and Yogo 2005), small violations of the exclusion restriction may still result in large biases. We therefore probe two additional observable implications from our theoretical argument. In both of them, we are able to capitalize on a larger F-statistic.

First, we ask whether protesters mobilized earlier in counties with a weaker decline in pollution levels. While the first protest occurred on August 13, 1989 (in Dresden), it took about two to three months until the first protest occurred in other counties (76 days on average). Second, we ask whether pollution only matters in the heat of the moment or whether there is evidence for a more sustained mobilization rooted in antiregime sentiment developing in the years before the 1989 protests. To answer this question, we turn to the analysis of complaint letters sent by East Germans to the regime.

Pollution and protest timing

To measure the timing until protests emerged in a county, we use a categorical variable indicating whether a protest occurred (i) within three months after the first protest (75% of all counties), (ii) later (18%), or (iii) never (7%). We then regress an indicator variable for each category separately on the average annual decline in SO_2 (which we instrument using the average annual change in thermal inversion strength, as before). An alternative analysis strategy could be to use the number of days until the first protest as a dependent variable. We refrain from using this approach as a subsetting to counties with at least one protest could introduce a sample selection bias. Our strategy is similar to that of Angrist (2001).

The results indicate that the probability for early protesting increases in places with a weaker reduction in pollution, while it declines for late protesting (see table 2). The IV estimates suggest that a 1 standard deviation smaller reduction in pollution increases the propensity for early protesting by 13 percentage points, while the probability for late protesting declines by 10 percentage points. However, the later estimate fails to reach the .05 significance level. Since we find no effect on the probability of protest occurrence in a county, the results imply that pollution affects the intensity of mobilization but not the likelihood of protesting.

Table 2. Effect of Change in SO_2 Immissions on Probability of Protesting

	OLS			IV		
	Early	Late	Never	Early	Late	Never
ΔSO_2	.42*	−.38*	−.05	−.71*	−.58	−.13
	(.17)	(.15)	(.11)	(.35)	(.31)	(.21)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Emission groups FE	Yes	Yes	Yes	Yes	Yes	Yes
F (instrument)				30.86	30.86	30.86

Note. The effect of the change in SO_2 immissions on the probability of early protesting, late protesting, and no protesting across 216 counties between August 1989 and April 1990. Covariates: annual change in temperature and precipitation, 1980–88. Instrument: average thermal inversion strength (1980–88). Standard errors in parentheses. $N = 216$. OLS = ordinary least squares; IV = instrumental variable; FE = fixed effects.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Subjecting these results to the same robustness tests as reported above, we find the same pattern in the point estimates when using alternative instruments, adjusting for temperature and precipitation bins rather than the continuous covariates and additional covariates, as well as including a spatially lagged dependent variable and spatially lagged error term or using dust immissions as an independent variable (tables C.12–C.17). However, in some of these robustness tests, the coefficient estimates shrink and fail to reach the .05 statistical significance level. Therefore, our confidence in these results is somewhat lower as compared to the results in the main analysis above.

Pollution and complaint letters

East German citizens had the opportunity and the constitutional right to write letters with complaints to the regime. This institution was designed to learn about citizens' grievances while preventing the emergence of an organized opposition (Zatlin 1997). Our data on complaint letters come from the Potsdam Grievance Statistic File (Class, Kohler, and Krawietz 2018). Collected from previously classified documents, this data set includes information on the number of letters by topic and time period across 184 counties in the GDR between 1980

Table 3. Effect of SO_2 Immissions on Environmental Protection Letter Volume

	OLS				IV			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
SO_2	.61***	.61***	1.29***	.30**	.77*	.67*	1.46***	.42*
	(.18)	(.18)	(.25)	(.09)	(.37)	(.33)	(.29)	(.18)
Covariates	No	Yes	Yes	Yes	No	Yes	Yes	Yes
County FE	No	No	Yes	No	No	No	Yes	No
Lagged DV	No	No	No	Yes	No	No	No	Yes
F (instrument)					25.26	29.15	1,114.22	33.90
N	1,517	1,517	1,517	1,253	1,517	1,517	1,517	1,253

Note. Effect of SO_2 immissions (t/m^3) on the number of letters related to environmental protection per 10,000 capita and day in East Germany's counties between 1980 and 1989. Covariates: precipitation and temperature. Instrument: thermal inversion strength. Standard errors in parentheses. OLS = ordinary least squares; IV = instrumental variable; FE = fixed effects; DV = dependent variable.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

and 1988. On average, about 3.3% of all letters are related to environmental pollution.[21]

We use these data to construct a county-year panel of the number of letters per 10,000 capita and day. Taking advantage of the repeated observations for each county, we expand the baseline specification to include either county fixed effects or the lag of the dependent variable.[22] While the county fixed effects remove all time-invariant confounding, the lagged dependent variable helps to address the concern that the number of letters written in the past might have an effect on future SO_2 immissions if the regime is responsive to letter writers (which is a version of time-varying confounding). We continue to instrument SO_2 immissions using the thermal inversion strength, to cluster standard errors at the county level, and to exclude the county of Berlin.

Table 3 displays the results, and table C.18, the first-stage estimates. The results suggest that higher levels of SO_2 immissions increase the number of letters per capita. Comparing the OLS estimates with the 2SLS estimates (models 1–4 vs. models 5–8) suggests that the confounding leads us to underestimate the effect of pollution on the numbers of letters related to environmental protection. In substantive terms, the estimated effects are large, but the magnitude varies with the specification. The smallest 2SLS estimates suggests that an increase of about 1 standard deviation in SO_2 increases the number of complaint letters related to the environment by about 12% at the sample mean.

We subject these results to similar robustness tests as reported above. We find that alternative definitions of the instrument tend to reduce the first stage (table C.19), and point estimates tend to be smaller depending on the specification (table C.21). We find the same pattern in the point estimates when adjusting for temperature and precipitation bins rather than the continuous covariates (table C.22), as well as including a spatially lagged dependent variable and spatially lagged error term (table C.24). In additional analysis reported in the appendix, we find a similar pattern when it comes to dust immissions (table C.23) and when we replicate the entire analysis using the proportion of letters related to environmental protection (tables C.25–C.29). For this analysis, we find that an increase of about 1 standard deviation in SO_2 increases the share of letters that focus on environmental pollution and the volume of letters per capita by about 1 percentage point. This implies an increase of about 30% relative to the sample mean.

Discussion

The results support the hypothesis that environmental pollution causes an increase in antiregime mobilization. We conclude our empirical analysis with a number of more suggestive findings that paint a broader picture of the relationship between pollution and dissent in the former GDR.

21. For more details on these data, see app. sec. A.1, where we also present three exemplary letters related to the environment.

22. We also implemented a two-way fixed effect estimator by adding year fixed effects. We note that we find this strategy less suitable for the data at hand as there is little local time variation to leverage. When we decompose the observed variance for SO_2 using an ANOVA, we find that county differences explain 78.8% of the variation, and year differences account for 19.8% of the variation, which leaves 1.4% of variance to estimate the effect in a two-way fixed effect estimator (see table C.30). Using this little variation, we obtain no statistically significant effects (table C.20).

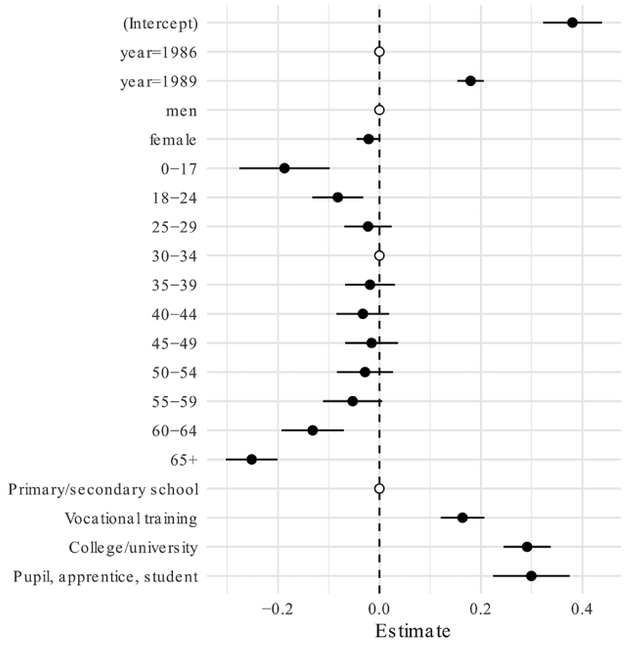

Figure 3. Ordinary least squares estimates with robust standard errors. Effect of demographic characteristics on respondents interest to listen to a radio program related to nature/environmental protection in two surveys from November 1985 and October 1989. $N = 6{,}155$.

First, our measures of dissent are at the county level; that is, they measure aggregated individual actions. While we can demonstrate that pollution affects these actions, we cannot characterize who exactly expressed discontent. To provide some tentative insights on the individuals who are most concerned about pollution, we analyze survey data collected by the state media agency. These data include questions on the topics citizens wish to hear more about in the media. More information about these data can be found in appendix section A.5. In figure 3, we show a regression of a series of demographic variables on a measure of interest in broadcasts on environmental protection. As one would expect, we find that education correlates positively with interest. We also find that there are gender differences and that there is a U-shaped relationship for age—younger and older respondents are much less interested than those age 25–54 years. Finally, we find that interest in the environment grew between 1985 and 1989, which is consistent with the findings reported above.

Second, our analysis abstracts away from the role of the regime. On the one hand, our results suggest that the regime was, to some extent, able to reduce pollution—recall that pollution levels are decreasing throughout our study period. On the other hand, we find that dissent is still driven by pollution. One interpretation is that this decrease was perceived as "too little too late" by many citizens. Some citizens may have also shied away from voicing their concerns, fearing to be targeted by the regime, which considered any complaint letter as a "critique of socialism" (Class et al. 2018, 98).[23] In those places that experienced smaller decreases in pollution, citizens eventually protested in order to establish a new regime. It should be highlighted, however, that environmental grievances were obviously not the only reason for the mass mobilization in 1989 that culminated in the fall of the Berlin Wall.

Third, we emphasize that while our analysis is unique in providing quantitative evidence for the role of pollution, it is consistent with the work by historians who note that environmental concerns were important in the final years of the GDR (Opp and Gern 1993). In fact, historians suggest that groups of environmentally conscious citizens constituted the "organizational backbone" of the East German revolution (Huff 2015, 410). Under the umbrella of the church, environmentally conscious citizens organized in so-called *Umweltgruppen* (environmental groups). While collective action of these groups was initially limited to bicycle demonstrations and information events, it evolved into the formation of opposition networks that demanded far-reaching reforms and mobilized the protests in 1989.

CONCLUSION

Many countries struggle with pollution and the health issues caused by it. In this article, we contribute to existing research on the effect of pollution on political outcomes in democracies, by showing that pollution also has profound implications for authoritarian politics. In particular, we demonstrate that pollution affects citizens' behavior, leading to both individual and collective expressions of discontent.

To the extent that pollution is a consequence of economic growth or performance, our empirical results suggest a novel trade-off to rulers: not only must they supply some income to citizens to satisfy the economic performance constraint on their rule (e.g., Fearon 2011), but they also need to keep track of pollution. Our empirical results imply that pollution can be a profound driver for antiregime sentiment, leading to large-scale protests. Future work could investigate more explicitly the mechanism behind this result, determining whether citizens simply punish the regime, learn about (the lack of) policy-making competence, or update their beliefs about the likelihood of repression. In addition, future research should investigate the effect of pollution on outcomes in authoritarian polities in contexts in which there is more local variation in pollution over time, as our analysis tends to largely rely on (local) cross-sectional variation.

There are three structural variables that may have amplified the effects of pollution in the GDR. First, despite lagging behind

23. There is evidence that the Stasi had access to the complaint letters and that it had no "reservations to use this information on its behalf" (Hecht 2001, 416).

West Germany in terms of economic development, the GDR was a comparatively high-income autocracy. While there are reasons to believe that concerns about environmental pollution increase with income, including changing attitudes (e.g., Inglehart 1971), it is an open empirical question to what extent our findings generalize to lower-income polities. Second, some citizens in the GDR had access to West German TV, which covered environmental problems and the rise of the Green Party in West Germany. Third, the existence of locally rooted church groups proved to be a cradle in which antiregime attitudes could be nurtured and environmental concerns discussed. While discerning the importance of these is beyond the scope of this article, we speculate that the internet and social media can function as substitutes in other polities.

In addition to evaluating the importance of media availability and grassroots organizations, we draw attention to the importance of investigating when and how regimes are able to prevent environmental pollution from mobilizing the masses. In the context of the 1989 protests in the GDR, the regime failed to prevent the protests. Yet, we expect that regimes in other contexts might be more successful through their use of repression or co-optation. When citizens took to the streets in 1989, the Soviet Union was beginning to fall apart as protests took place in other satellite states. This certainly reduced the likelihood of repression and might have elevated the mobilizing effect of pollution.

Our work highlights that environmental pollution has a destabilizing effect on authoritarian regimes. This is relevant to our predictions about the future of China and other economically prospering authoritarian polities. While anthropogenic pollution is likely to decrease in the coming decades in these countries, natural air pollution due to forest fires as a consequence of climate change is expected to increase, with potentially similar consequences for politics. This points to yet another reason as to why climate change is set to become a major political force with the potential to spark revolutionary change or conflict (Koubi 2019; Salehyan 2008).

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