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Efficacy of Command-and-Control and Market-Based Environmental Regulation in Developing Countries

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Abstract

Like their counterparts in industrialized countries, environmental regulators in developing countries rely principally on two types of instruments: command-and-control (CAC) policies, such as emissions and technology standards, and to a lesser extent, market-based instruments (MBIs), such as emissions fees and tradable permits. But these regulators often lack the capacity to implement, monitor, and enforce CAC and MBI policies. As a result, the efficacy of those policies is an empirical matter. We review emerging experimental and quasi-experimental evidence on CAC and MBI policies in developing countries, specifically, from 32 studies of CAC policies and 8 studies of MBIs. Although drawn from a small and decidedly nonrandom sample of countries and policy types, the evidence clearly indicates that CAC and MBI policies can have significant environmental benefits in developing countries. In addition to cataloging and reviewing this evidence, we discuss data and methodological challenges to augmenting it and suggest directions for future research.

1. INTRODUCTION

The global South is home to the world's worst environmental problems. For example, the 10 cities with the world's worst air quality are all in developing countries, as are many of the most polluted rivers (Marlier et al. 2016, WHO 2016). This pollution has serious adverse consequences at both local and global levels. The World Health Organization (WHO) estimates that pollution causes 8.4 million deaths per year in developing countries, including 6.7 million from air pollution, 0.8 million from water pollution and poor sanitation, and 1.0 million from toxic and industrial wastes (GAHP 2014, Landrigan & Fuller 2015). And each year, developing countries, led by China and India, contribute roughly two-thirds of global greenhouse gas emissions (Eur. Comm. 2012).

Like their counterparts in industrialized countries, environmental regulators in developing countries rely principally on two types of instruments: command-and-control (CAC) policies, and to a lesser extent, market-based instruments (MBIs). CAC regulations such as emissions standards and technology standards mandate how much and/or how polluters abate. MBI regulations, by contrast, create economic incentives for abatement. The main types are emissions fees (fees per unit of emissions), marketable permits (emissions allowances that can be traded among polluters), and environmental taxes (taxes on inputs or outputs).

A salient feature of CAC and most types of MBI policies is that they depend on environmental regulatory capacity to be effective: Regulators must check compliance and sanction violators. In developing countries, however, regulatory monitoring and enforcement are inhibited by gaps and inconsistencies in written legislation, weak (undermanned and underfunded) regulatory institutions, a lack of political will for stringent enforcement, a shortage of public pollution control facilities like wastewater treatment plants, and an abundance of difficult-to-monitor small and informal firms (Eskeland & Jimenez 1992, Russell & Vaughan 2003). As a result, the efficacy of CAC and MBI policies in developing countries is an empirical matter: We need rigorous evaluations to understand whether and under what conditions they generate the intended environmental benefits.

As discussed below, the past decade has seen a significant uptick in studies using rigorous empirical methods to evaluate the effects of CAC and MBI regulations in developing countries. To our knowledge, a comprehensive review of this evidence has yet to appear. This article aims to help fill that gap. To make the review both manageable and focused, we have used the following criteria for including studies. We focus on those that

- are published in peer-reviewed journals;
- examine policies in developing (versus transitioning) countries;
- analyze "brown" regulations addressing air, water, solid waste, and hazardous waste pollution, not "green" regulations governing natural resources such as fisheries, forests, and agriculture;
- analyze policies that require environmental regulators to check compliance and sanction violators;
- use rigorous impact evaluation methods that aim to control for confounding factors; and
- address the efficacy of regulations in generating benefits.

In addition, we put more emphasis on studies using longitudinal data than on those using cross-sectional data.

The remainder of the review is organized as follows. Section 2 presents a simple heuristic model of a manufacturing plant's pollution abatement decision. The purpose is to underpin the discussion of the literature. Section 3 briefly discusses data and methodological challenges of evaluating environmental regulatory efficacy in developing countries. Section 4 examines CAC regulation and includes subsections on stationary source regulations and mobile source regulations.

Section 5 examines MBI regulation, with subsections on environmental fees and tradable permits. The final section summarizes and discusses the findings.

2. HEURISTIC MODEL

To facilitate the discussion of the literature that follows, this section briefly presents a simple often-used heuristic model of a plant's choice of how much pollution to emit, or alternatively, how much to abate (e.g., Pargal & Wheeler 1996, World Bank 2000). The model assumes that plants consider two types of costs when choosing an optimal level of emissions. First, both regulators and other external parties—including local communities, capital markets, and consumers—penalize the plant for polluting. The expected marginal (pecuniary and nonpecuniary) penalty (EMP) increases with the level of emissions because each additional unit of emissions generates greater damages to human health and the environment. Second, plants must pay to abate emissions by investing in pollution control and prevention. The marginal abatement cost (MAC) decreases with the level of emissions because these investments generate diminishing returns. The plant will choose a level of emissions that minimizes the sum of these two types of costs—that is, the level at which the EMP is equal to the MAC.

As illustrated in **Figure 1**, the plant's EMP schedule increases with the level of emissions, and its MAC schedule decreases with the level of emissions. The plant's cost-minimizing level of emissions, E_1, is determined by the intersection of the EMP_1 and MAC_1 schedules. If the plant is required by law to meet an emissions standard, R, the EMP schedule shifts up at R due to mandated fines and other regulatory penalties. Policies that enhance regulatory or nonregulatory pressures will shift the EMP schedule up (to EMP_2), and those that cut abatement costs will shift the MAC schedule down (to MAC_2). Both types of policies will reduce E_1.
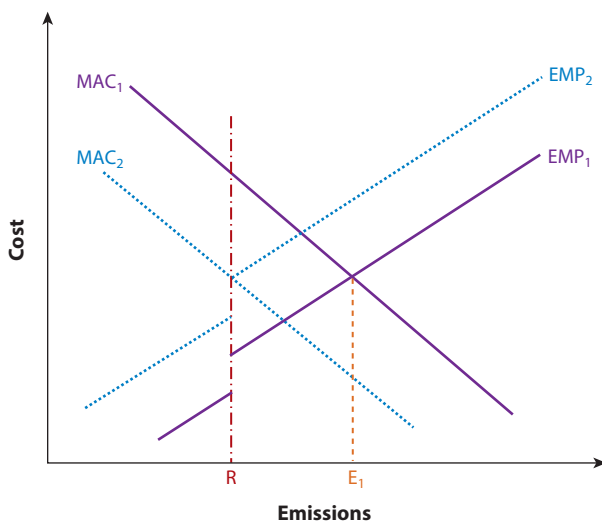
Figure 1

A manufacturing plant's choice of emissions. The plant's cost-minimizing level of emissions, E_1, is determined by the intersection of the EMP_1 and MAC_1 schedules. The EMP schedule shifts up at R due to mandated fines and other regulatory penalties. Policies that enhance regulatory or nonregulatory pressures will shift the EMP schedule up (to EMP_2), and those that cut abatement costs will shift the MAC schedule down (to MAC_2). Both types of policies will reduce E_1. Abbreviations: E, emissions; EMP, expected marginal penalty; MAC, marginal abatement cost; R, emissions standard.

The fundamental issue observed by the literature is that regulatory pressure is weak for the reasons listed in the introduction: inadequate regulatory institutions, a lack of political will for stringent enforcement, a shortage of public pollution control facilities, and an abundance of difficult-to-monitor small and informal firms. In terms of our graphical model, the result is that the EMP schedule lies close to the horizontal axis. Many of the studies reviewed in subsequent sections effectively test whether imposition of a CAC or MBI policy shifts that schedule up and shifts equilibrium emissions to the left.

3. CHALLENGES IN EVALUATING ENVIRONMENTAL REGULATORY EFFICACY

Conducting rigorous empirical research on the efficacy of CAC and MBI regulation in developing countries is challenging for several reasons. First, credible data on environmental outcomes—in particular, facility-level data collected by regulators—are scarce. In most developing countries, such data simply do not exist. When they do, they are often self-reported and unverified. Also, they often suffer from selection bias: Plants that regularly self-report tend to be superior environmental performers. Given these problems, many of the studies we review in this article rely on other types of data. For example, among the 32 studies examining CAC regulations discussed below, only six rely on official plant-level data (**Table 2**). The rest use environmental quality data at the level of an administrative unit, monitoring station, or vehicle, or they use original plant-level survey data.

Second, disentangling the effects of a specific regulatory policy on environmental performance from the effects of other regulatory policies can be difficult. Government programs that address serious pollution problems are often multifaceted, entailing a suite of policies implemented concurrently. For example, China implemented a portfolio of policies to quickly improve air quality in Beijing and other cities during the 2008 summer Olympic Games, including closing major polluting facilities, mandating installation of abatement devices in coal-fired power plants, and imposing more stringent emissions standards (He et al. 2016). And in Santiago, Chile, regulators rely on CAC emissions standards, tradable permits, license-based driving restrictions, and episodic plant closures to improve air quality (Mullins & Bharadwaj 2012).

Third, disentangling the effects of a specific regulation on environmental performance from the effects of omitted variables can be challenging. One reason is that regulators and communities surrounding dirty plants may pressure those plants to improve their environmental performance, a phenomenon that occurs all over the world but is arguably particularly prominent in developing countries, where community pressure sometimes drives variation in environmental regulatory stringency (Blackman & Bannister 1998, Pargal & Wheeler 1996). A study that failed to control for community pressure might overstate the effect of regulation.

Finally, reverse causality can confound treatment effects estimates. For example, regulators often target particularly dirty plants for enforcement (e.g., Blackman et al. 2010). A study of the effect of enforcement on environmental outcomes that did not control for that targeting could generate a spurious negative correlation between enforcement and environmental performance. This is a challenge in evaluating the efficacy of regulations in both industrialized and developing countries.

4. COMMAND-AND-CONTROL REGULATION

Overall, the emerging evidence on the effectiveness of CAC regulation in developing countries indicates that it can generate intended benefits; of the 32 studies summarized below, 24 (75%) find that CAC regulation has had some benefit (**Tables 1** and **2**). The first subsection below examines the evidence on regulating stationary source pollution, with further subsections discussing the

Table 1 Evidence on the effects of command-and-control and market-based instrument environmental regulation in developing countries

Study[a]	Instrument	Study area, sector	Regulation	Outcomes	Data	Methods	Results
Stationary sources: air and water, panel data							
Greenstone & Hanna (2014)	CAC	India	SCAPs for improved air quality and mandates for catalytic converters; NRCPs	PM, SO$_2$, and NO$_2$ air pollution; BOD, Fcoli, and DO water pollution; infant mortality	City-level	DID	SCAPs and catalytic converter mandates improved air quality; catalytic converter mandates reduced infant mortality; NRCPs had no discernible effect
Duflo et al. (2013)	CAC	Gujarat, India	Various	Accuracy of third-party audit reports, regulatory compliance	Plant-level	RCT of intervention aimed at improving quality of third-party audits	Intervention improved accuracy of audit reports and regulatory compliance
Jin & Lin (2014)	CAC	China	Province-level air and water pollution control targets set under five-year plan	COD water pollution, SO$_2$ air pollution	Province-level	FE OLS	Targets spurred reductions in COD and SO$_2$
Dasgupta et al. (2001)	CAC	Zhenjiang, China	Various	TSS air pollution; COD and TSS water pollution	Plant-level	Simultaneous equations	Regulatory inspections caused reduction in both air and water pollution
Stationary sources: air and water, cross-sectional data							
Dasgupta et al. (2000)	CAC	Mexico	Various	EMS adoption, self-reported regulatory compliance	Plant-level	2SLS	Regulatory inspections spurred EMS adoption, which spurred compliance
Escobar & Chávez (2013)	CAC	Mexico City, Mexico	Various	Compliance (among others)	Plant-level	Ordered probit (among others)	Regulatory inspections spurred compliance
Féres & Reynaud (2012)	CAC	Sao Paulo, Brazil	Various	Total cost, regulatory pressure, pollution emissions	Plant-level	3SLS	Intensity of CAC regulation was correlated with pollution abatement expenditure
Seroa da Motta (2006)	CAC	Brazil	Various	Several environmental management practices	Plant-level	OLS	Regulatory sanctions spurred adoption of environmental practices
Zhao et al. (2015)	CAC	China, electric power sector	Various	CO$_2$ emissions	Plant-level	OLS	Strength of CAC regulations helps explain carbon emissions

(Continued)

Table 1 (*Continued*)

Study[a]	Instrument	Study area, sector	Regulation	Outcomes	Data	Methods	Results
Stationary sources: air, panel data							
Mullins & Bharadwaj (2012)	CAC	Santiago, Chile	Environmental episode days	Ambient PM10 air pollution, all-cause mortality	Day-level	Matched DID	Episode days reduced PM10 by one-fifth on day of implementation and cut mortality among elderly
Troncoso et al. (2012)	CAC	Santiago, Chile	Environmental episode days	CO, NOx, SO2, PM2.5, PM10	Day-level	Event study model	Episode days reduced CO, NOx, PM2.5, and PM10 but not SO2
Coria (2009)	CAC	Santiago, Chile	Environmental episode days and permit trading	Conversion to natural gas	Plant-level	Duration model	Energy prices, not regulation, drove switch to natural gas
He et al. (2016)	CAC	China	Beijing 2008 summer Olympics air quality regulations	PM10 and mortality	City-level	DID	Regulations reduced PM10 by 10% and all-cause mortality by 8%
Chen et al. (2013)	CAC	China	Beijing 2008 summer Olympics air quality regulations	Air pollution index (NO2, SO2, PM10), satellite AOD	City-level	DID	Regulations reduced air pollution index by one-quarter
Tanaka (2015)	CAC	China, electric power sector	Two Control Zone policy	Infant mortality	County- and prefecture-level	DID	Regulations reduced infant mortality by one-fifth
Hanna & Oliva (2015)	CAC	Mexico City, Mexico	Refinery closure	SO2 air pollution, labor supply	Census tract-level	DID	Plant closure reduced SO2 pollution by one-fifth and increased hours worked by 4%
Stationary sources: water, panel data							
Kahn et al. (2015)	CAC	China	2006 border pollution regulations	COD	Monitoring station-level	DID	Regulations led to significant reductions in COD
Liu et al. (2017)	CAC	Jiangsu Province, China, textile sector	Discharge standards	COD and labor demand	Plant-level	DID	Standards reduced COD discharges by more than one-fifth, and reduced labor demand by 7%

(*Continued*)

Table 1 (*Continued*)

Study[a]	Instrument	Study area, sector	Regulation	Outcomes	Data	Methods	Results
Stationary sources: water, cross-sectional data							
Wang (2002)	CAC	China	Various	Abatement expenditures	Plant-level cross-section	IV model	Unable to discern effect
Blackman & Kildegaard (2010)	CAC	León, Guanajuato, Mexico	Various	Adoption of clean technologies	Plant-level	Bivariate probit	Unable to discern effect
Mobile sources: driving restrictions							
Eskeland & Feyzioughu (1997)	CAC	Mexico City, Mexico	License plate–based driving restrictions	Fuel consumption and vehicle ownership	City-level longitudinal	See text	Restrictions increased fuel consumption
Davis (2008)	CAC	Mexico City, Mexico	License plate–based driving restrictions	CO, NO_2, O_3, NO_x, SO_2, gasoline sales, vehicle registration and sales, bus ridership, taxi prices	City-level longitudinal	RD	Air pollution did not decline and increased during weekdays; vehicle registration and sales increased and bus ridership decreased
Gallego et al. (2013a)	CAC	Mexico City, Mexico	License plate–based driving restrictions	CO	City-level longitudinal	RD	CO decreased in short run but not long run
Sun et al. (2014)	CAC	Beijing, China	License plate–based driving restrictions	City-wide traffic speed, inhalable particles	City-level longitudinal	DID	Restrictions increased city-wide traffic speed
Viard & Fu (2015)	CAC	Beijing, China	License plate–based driving restrictions	Air pollution index (NO_2, SO_2, PM10), TV viewership	City-level longitudinal	DID	Restrictions reduced air pollution by about one-fifth and increased TV viewership 9–17% for workers with "discretionary work time"
Lu (2016)	CAC	Beijing, China	License plate–based driving restrictions (modifications)	Air pollution index (NO_2, SO_2, PM10)	City-level longitudinal	RD	2009 weakening of policy led to increases in pollution; 2011 strengthening led to reductions

(*Continued*)

Table 1 (*Continued*)

Study[a]	Instrument	Study area, sector	Regulation	Outcomes	Data	Methods	Results
Bonilla (2016)	CAC	Bogotá, Colombia	License plate–based driving restrictions	CO, fuel consumption, vehicle registration, new vehicle sales	City-level longitudinal	RD	Early and late phases of program had no effect on CO or vehicle use; some evidence that the late phase increased fuel consumption, vehicle ownership, and CO in morning peak hours
Zhang et al. (2017)	CAC	Bogotá, Colombia	License plate–based driving restrictions	PM10, NO, NO_2, NO_x, O_3, SO_2	City-level longitudinal	RD	Although effects of restrictions vary across pollutants, no significant improvements in overall air quality
Carrillo et al. (2016)	CAC	Quito, Ecuador	License plate–based driving restrictions	CO	City-level longitudinal	DDD	Restrictions reduced CO pollution by 9–11% during peak traffic hours
De Grange & Troncoso (2011)	CAC	Santiago, Chile	License plate–based driving restrictions	Automobile, metro, and bus trips	City-level longitudinal	RD	Permanent restrictions have not affected use of private vehicles, but additional restrictions reduced private vehicle use by 6% and increased metro use by 3%
Miscellaneous							
Oliva (2015)	CAC	Mexico City, Mexico	Emissions standards	Cheating incidence, vehicular emissions (among others)	Vehicle-level panel	See text	10% of car owners cheated on emissions tests; eliminating cheating would significantly reduce vehicular emissions
Kathuria (2002)	CAC	Delhi, India	Various	SPM, NO_x	City-level longitudinal	Event study	Unable to discern effect

(*Continued*)

Table 1   (Continued)

Study[a]	Instrument	Study area, sector	Regulation	Outcomes	Data	Methods	Results
China's pollution levy system							
Wang (2002)	MBI	National	Water	Abatement investments, expenditures	Plant-level cross-section	IV model	Higher effective levy rate increases abatement investments and expenditures
Wang & Wheeler (2005)	MBI	National	Air and water	SO₂ air pollution, COD water pollution	Plant-level cross-section	Simultaneous equations	Higher effective levy rate decreases pollutant emissions
Jiang & McKibbin (2002)	MBI	National	Air, water, and solid waste	Pollution intensities of waste gas, waste water, and solid waste	Province-level panel	Simultaneous equations	Higher effective levy rate decreases pollution intensities
Jin & Lin (2014)	MBI	National	Air and water	SO₂ air pollution, COD water pollution	Province-level panel	FE OLS	Higher effective levy rate decreases air pollution but not water pollution
Dasgupta et al. (2001)	MBI	Zhenjiang	Air and water	TSS air pollution; COD and TSS water pollution	Plant-level panel	Simultaneous equations	Regulatory inspections reduce air and water pollution
Lin (2013)	MBI	Unidentified municipality	Water	COD water pollution	Plant-level panel	IV model	Regulatory inspections increase plants' reported total and above-standard water pollution
Chile's tradable permit program							
Montero et al. (2002)	MBI	Santiago	Air	Adoption of natural gas	Plant-level cross-section	Logit	Permit trading did not encourage switch to natural gas
Coria (2009)	MBI	Santiago	Air	Adoption of natural gas	Plant-level panel	Duration model	Energy prices, not regulation, drove switch to natural gas

[a]Studies are listed in the order they are discussed in the text.

Abbreviations: 2SLS, two-stage least squares; 3SLS, three-stage least squares; AOD, aerosol optical depth; BOD, biochemical oxygen demand; CAC, command-and-control; CO, carbon monoxide; CO₂, carbon dioxide; COD, chemical oxygen demand water pollution; DDD, triple difference-in-differences; DID, difference-in-differences; DO, dissolved oxygen; EMS, environmental management system; Fcoli, fecal coliforms; FE, fixed effect; IV, instrumental variable; MBI, market-based instrument; NO₂, nitrogen dioxide; NOₓ, nitrogen oxides; NRCP, National River Conservation Plan; O₃, ozone; OLS, ordinary least squares; PM, particulate matter; PM2.5, particulate matter <2.5 microns; PM10, particulate matter <10 microns; RCT, randomized controlled trial; RD, regression discontinuity; SCAP, Supreme Court Action Plan; SO₂, sulfur dioxide; SPM, suspended particulate matter; TSS, total suspended solids.

Table 2 Studies on the effects of command-and-control (CAC) and market-based instrument (MBI) environmental regulation in developing countries

Study type, data type	Number	Number with benefit	Countries (number of studies)
Command-and-control: stationary sources			
Air and water			
Panel	4	4	India (2), China (2)
Cross-sectional	5	5	Mexico (2), Brazil (2), China (1)
Air only			
Panel	7	6	Chile (3), China (3), Mexico (1)
Water only			
Panel	2	2	China (2)
Cross-sectional	2	0	China (1), Mexico (1)
Total	20	17	
Command-and-control: mobile sources			
Driving restrictions	10	6	Mexico (3), China (3), Colombia (2), Ecuador (1), Chile (1)
Miscellaneous	2	1	India (1), Mexico (1)
Total	12	7	
Total CAC	32	24	China (12), Mexico (8), Chile (4), India (3), Brazil (2), Colombia (2), Ecuador (1)
Market-based instrument: pollution levies			
Air, water, solid waste			
Panel	1	1	China (1)
Air and water			
Panel	2	2	China (2)
Cross-sectional	1	1	China (1)
Water only			
Panel	1	0	China (1)
Cross-sectional	1	1	China (1)
Total	6	5	
Market-based instrument: tradable permit			
Switch to natural gas			
Panel	1	0	Chile (1)
Cross-sectional	1	0	Chile (1)
Total	2	0	
Total MBI	8	5	China (6), Chile (2)

type of regulation examined (covering both air and water pollution, only air, and only water). The next subsection summarizes the evidence on mobile source pollution, focusing on increasingly popular license plate–based driving restrictions but also looking at other instruments.

4.1. Stationary Sources

We found 20 studies that focus on CAC regulations governing stationary sources, including nine on air and water pollution, seven on air pollution only, and four on water pollution only.

4.1.1. Air and water pollution. All of the four studies we found that use panel data to assess the effects of CAC regulations covering both air and water pollution conclude that at least some of these regulations have had benefits. Greenstone & Hanna (2014) examine the effects of CAC regulations implemented at the city level in India—specifically, Supreme Court Action Plans (SCAPs) for improved air quality, mandates for catalytic converters, and the National River Conservation Plan (NRCP). SCAPs typically impose a suite of policies, including fuel regulations, road building, and emissions standards for stationary sources. The NRCP focuses on improving water quality via domestic and industrial wastewater treatment. The authors use city-level data along with generalized difference-in-differences models to examine the effects of these policies on three measures of air pollution, three measures of water pollution, and infant mortality. They find that both SCAPs and catalytic converter mandates generated substantial improvements in air quality, and the catalytic converter mandate led to modest reductions in infant mortality. The NRCP, however, had no discernible effects.

To our knowledge, the only published study of CAC regulations in a developing country based on a randomized controlled trial is that by Duflo et al. (2013). The authors evaluate the effect of a randomly assigned intervention aimed at improving the responsiveness of industrial polluters to various CAC environmental regulations in Gujarat, India. The intervention altered the market structure of third-party environmental audits, which is the primary means by which regulators monitor compliance with CAC policies. Specifically, for randomly selected plants that received the intervention, the auditors were paid from a central pool rather than by the plant, were randomly assigned to inspect plants instead of having long-standing responsibilities for certain plants, were monitored via follow-up visits replicating their inspections, and were paid conditional on their reporting accuracy. Duflo et al. find that the intervention caused auditors to report more truthfully and caused plants to reduce emissions, presumably because they understood that monitoring of noncompliance was more reliable. From the perspective of the present review, these results clearly indicate that CAC regulations can be effective.

Two studies use panel data to examine CAC regulations in China. Jin & Lin (2014) use 1992–2008 province-level panel data along with fixed-effects models to examine the effect of, among other things, province-level pollution control targets for chemical oxygen demand (COD) water pollution and sulfur dioxide air pollution. Provincial officials' promotions are linked to compliance with these targets, which are set under China's five-year plans. Jin & Lin find that the targets spur reductions in both COD and sulfur dioxide. Dasgupta et al. (2001) use 1993–1997 firm-level data to analyze the effect of regulatory inspections on polluting emissions (total suspended particulates air pollution, COD, and total suspended solids water pollution). To control for the endogeneity of inspections, they estimate a system of simultaneous equations. They conclude that the inspections caused reductions in both air and water pollution.

Finally, five studies, which on average are somewhat older than those summarized above, use cross-sectional plant-level data to examine the effects of CAC regulations on multiple types of pollution. In some cases, the data and/or empirical design have limitations. However, the results are consistent: All studies find that CAC policies are linked to some type of environmental practice or benefit. Both Dasgupta et al. (2000) and Escobar & Chávez (2013) examine, among other things, effects of regulatory inspections in Mexico. Dasgupta et al. (2000) find a link between inspections and environmental management system adoption, and in turn, a link between adoption and self-reported regulatory compliance. Escobar & Chávez (2013) identify a correlation between inspections and compliance reports from those inspections. Féres & Reynaud (2012) find that a measure of the intensity of CAC regulation is correlated with pollution abatement expenditure in Brazil. Seroa da Motta (2006) concludes that regulatory sanctions help explain the number of environmental practices that polluters adopted in Brazil. Finally, Zhao et al. (2015) find that

self-reported strength of CAC regulations helps explain carbon emissions from Chinese power plants.

4.1.2. Air pollution. Seven studies use panel data to examine the effects of CAC air pollution regulations. All but one find that these regulations have had some benefits.

4.1.2.1. Environmental episode days in Santiago, Chile. In 1997, Chilean regulators established an "environmental episode" policy that imposes additional controls on both stationary and mobile sources in Santiago on days when coarse particulate air pollution (PM10) is projected to exceed defined thresholds. These controls include shutting down major stationary sources, prohibiting the burning of biomass for home heating, and including additional vehicles in the city's driving restrictions program (see Section 4.2.1). Mullins & Bharadwaj (2012) examine the regulations' effect on PM10 air pollution and all-cause mortality. They use day-level data along with a matched difference-in-differences approach, essentially comparing changes in outcomes on days following declaration of an environmental episode with changes in outcomes on similar days with similar pollution levels prior to the implementation of the 1997 regulation. They find that the regulation reduced PM10 by approximately one-fifth on the day of implementation and cut mortality among the elderly. Both effects persisted on days following the environmental episode. Troncoso et al. (2012) use similar data along with a simpler event study approach to examine the effects of environmental episode days on a broader set of air pollutants, including carbon monoxide, nitrogen oxides, sulfur dioxide, and fine particulates (PM2.5). They find that the regulation cut carbon monoxide, nitrogen oxides (both emitted mainly by vehicles), and both coarse and fine particulates but not sulfur dioxides (mainly emitted by point sources). Finally, Coria (2009) uses stationary source-level panel data along with a duration model to determine whether environmental episode days (as well as Santiago's emissions permit trading system) help explain these sources' decisions to switch en masse from relatively dirty fuels to natural gas in the late 1990s and early 2000s. She concludes that they did not. Rather, the falling price of natural gas was mostly responsible for the switch.

4.1.2.2. The 2008 Beijing Olympic Games. Two studies examine the effects on air quality and health outcomes of the suite of CAC regulations China put in place to quickly improve air quality in Beijing, neighboring cities, and other host cities during the 2008 summer Olympic Games. Implemented between late 2007 and late 2008, these regulations affected both stationary and mobile sources. The stationary source measures included closing (either permanently or temporarily) major polluting facilities, relocating others, halting large construction projects, mandating installation of abatement devices in coal-fired power plants, imposing more stringent emissions standards, and requiring oil and gas collection and recovery systems to be installed in gas stations, oil storage facilities, and tankers. Mobile source measures included increasing gas prices, ratcheting up mobile source emissions standards, restricting driving (see Section 4.2.1), and replacing all heavy-emitting vehicles. He et al. (2016) analyze the effect of all of these regulations on air pollution and mortality in Beijing, neighboring cities, and other host cities. They use city-month–level data on PM10 generated by ground monitoring stations in 34 cities (8 treatment cities and 26 control cities) along with generalized difference-in-differences models. They find that the Olympics regulations reduced PM10 by 10% and all-cause mortality by 8%. Chen et al. (2013) use similar data and methods to analyze the effect of the Olympics regulations on air quality. However, they focus on Beijing, use a different sample of cities and different measures of air pollution, and supplement air quality data from ground monitors with satellite-based measures of aerosol optical

depth. They find that the Olympics regulations reduced an air pollution index by a quarter during the games, but the effect dissipated quickly thereafter.[1]

4.1.2.3. Miscellaneous regulations on stationary sources. Tanaka (2015) analyzes the effect of China's 1998 Two Control Zone policy, which is aimed at reducing power plant emissions nationwide, on infant mortality. Applied in 175 prefectures where ambient air quality exceeded national standards, this policy shut down small inefficient power plants and required larger ones to install abatement devices. Using county- and prefecture-level panel data for 145 jurisdictions along with a difference-in-differences model, the author finds that the Two Control Zone policy reduced infant mortality by one-fifth.

Hanna & Oliva (2015) examine the effects on sulfur dioxide air pollution and labor supply of the 1991 closure of a highly polluting oil refinery in Mexico City. Although the study focuses on the link between air pollution reductions and labor supply, it also sheds light on the effects of the CAC mandate that shuttered the refinery. The authors use census tract–level panel data along with a generalized difference-in-differences model in which census tracts within 5 km of the refinery are considered to have been "treated." They find that in these areas, the closure reduced sulfur dioxide pollution by 20% and increased hours worked per week by 4%.

4.1.3. Water pollution. Two studies examine the effects of CAC water pollution regulations using panel data, and both find significant benefits. Kahn et al. (2015) focus on 2006 Chinese regulations aimed at reducing discharges of COD from plants just upstream from jurisdictional borders. The 2006 regulations tied local officials' promotions to their success in reducing such border pollution. The authors use 2004–2010 monitoring station–level panel data from 499 monitoring stations along China's seven major rivers along with difference-in-differences models to test whether these regulations met that goal, in effect comparing changes in pollution levels at monitoring stations just upstream from borders with changes at monitoring stations far from borders. They find that the regulation led to significant reductions in COD.

Liu et al. (2017) examine the effects on COD and labor demand of 2004 regulations mandating more stringent discharge standards for textile printing and dyeing plants in the Lake Tai region of Jiangsu Province, China. They use 2002–2007 plant-level data from 661 facilities along with difference-in-differences models, essentially comparing changes in outcomes at textile plants in the area affected by regulation with changes at plants elsewhere. They find that the regulations reduced COD discharges by more than 20%, reduced labor demand by 7%, and had stronger effects in certain types of plants, including those that were domestically owned.

Finally, two older studies using cross-sectional data examine the effect of CAC water pollution regulations. Neither is able to discern a significant effect. Wang (2002) uses plant-level data on more than 1,000 Chinese industrial firms along with instrumental variable models to examine the effect of CAC regulations (proxied by location in a designated environmentally sensitive zone and other variables) on abatement expenditures. Blackman & Kildegaard (2010) use plant-level data on leather tanneries in León, Mexico, along with bivariate probit models to examine the link between CAC regulations governing wastewater discharges (proxied by regulatory inspections) and adoption of clean tanning technologies.

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[1]In addition to these two quasi-experimental studies, a number of studies have focused on reported trends in air quality before and after the Olympic Games (see, e.g., Wang et al. 2009).

4.2. Mobile Sources

We found 12 studies that focus on CAC regulations governing mobile sources, including 10 on license plate-based driving restrictions, and two on other types of regulation.

4.2.1. License plate–based driving restrictions. License plate–based driving restrictions aim to reduce air pollution and traffic congestion by prohibiting drivers from using their vehicles one or more days a week based on the last digit of the license plate. Such policies have been implemented in at least a dozen developing country megacities worldwide, including Beijing, Delhi, Bogotá, Quito, Medellín, San José, São Paulo, and Santiago. Recently, these regulations have received considerable attention from economists, with 10 published studies. Findings have been decidedly mixed: Two studies have concluded that these programs have at least some perverse effects, two find no effects, and six find significant benefits.

4.2.1.1. Mexico City. Mexico's City's 1989 Day Without Driving (Hoy no Circula, HNC) program is probably the world's best known and most studied license plate–based driving restrictions initiative. Until the rules were changed in 2016 to exempt all vehicles that could pass emissions tests, the program prohibited vehicles more than eight years old from being driven one weekday per week and one Saturday per month both in the Federal District and in 19 neighboring counties from 5 AM to 10 PM. Eskeland & Feyziouglu (1997) evaluate HNC's effects on fuel consumption and vehicle ownership. They use historical data to predict counterfactual outcomes and then compare predicted and actual outcomes. They find that the program actually increased gasoline consumption, most likely because drivers purchased additional vehicles—often gas-guzzling, highly polluting clunkers—so that they could drive on the restricted day.

Almost a decade after that seminal study appeared, Davis (2008) revisited the issue using more comprehensive data and temporal regression discontinuity (interrupted time series) models that aim to identify breaks in trends at the time the program was first implemented. Outcomes analyzed were five types of air pollution (carbon monoxide, nitrogen dioxide, ozone, nitrogen oxides, and sulfur dioxide), gasoline sales, vehicle registration and sales, bus ridership, and taxi prices. Davis finds that, in general, air pollution did not decline as a result of HNC and actually increased during weekdays. In addition, vehicle registration and sales increased and bus ridership decreased.

Gallego et al. (2013b) use a regression discontinuity approach similar to Davis's (2008) but analyze only carbon monoxide and use models with different specifications (e.g., different lengths of the event window, different order polynomials). The results confirm that HNC did not reduce air pollution in the long run. However, the authors find that it did cut air pollution in the first several months after implementation, before drivers had a chance to fully adjust by, for example, buying additional cars.

4.2.1.2. Beijing. Beijing's license plate–based driving restrictions program was first implemented in 2008 as part of a collection of policies aimed at improving air quality ahead of the Beijing summer Olympic Games (see Section 4.1.2). For its first two-month implementation period, which coincided with the Games, the program prohibited driving every other day seven days a week for all but three hours a day (midnight to 3 AM). Afterward, it prohibited driving one day per week, first between 6 AM and 9 PM and later (2009) from 7 AM to 8 PM. Evaluating the effects of Beijing's driving restrictions program is challenging because it coincided with other air pollution control measures and because the one-day-a-week program was preceded by an every-other-day program. Sun et al. (2014) examine the one-day-a-week program's effects on city-wide traffic speed and inhalable particulates. They use day-level data along with a novel generalized

difference-in-differences identification strategy based on a plausibly exogenous absence of license plates ending in the digit 4, attributable to a cultural aversion to that number. They claim this strategy allows them to disentangle the program's effects from those of concurrent air quality measures. They find that driving restrictions succeeded in increasing average city-wide traffic speeds but had little effect on concentrations of inhalable particulate matter.

Viard & Fu (2015) examine the one-day-a-week program's effects on an air pollution index (of coarse particulates, nitrogen oxides, and sulfur dioxide) and labor supply, proxied by television viewership. Their strategy for disentangling the effects of the program on air quality from those of concurrent air pollution policies is to take advantage of not only the temporal variation in the policy but also the spatial variation in its effects related to the proximity of air quality monitoring stations to roads. They find that the program reduced air pollution by approximately one-fifth and increased television viewership 9–17% for workers with "discretionary work time." They posit that the program has been more effective than the HNC in Mexico City because purchasing additional vehicles to circumvent driving restrictions is more costly in Beijing, vehicles in Beijing are newer and cleaner, and public transportation in Beijing is cheaper and higher quality. In addition, they provide evidence that rates of compliance with Beijing's program are high.

Finally, Lu (2016) examines the effects of changes in the rules of Beijing's one-day-a-week program after it was first implemented in September 2009. Specifically, he examines an April 2009 decision to narrow by two hours the daily window during which restrictions were in force and a January 2011 decision to, among other things, increase the maximum fine for violations. He uses daily air pollution index data along with a regression discontinuity design similar to Davis's (2008). He finds that the 2009 weakening of the policy led to increases in pollution, and the 2011 strengthening led to reductions.

4.2.1.3. Bogotá. First implemented in 1998, Bogotá's driving restrictions policy has undergone three significant revisions. In its initial incarnation, it restricted driving private vehicles for four hours a day: two hours during the morning rush hour and two hours during the evening rush hour. In 2001, the evening restriction was extended to cover public vehicles. In 2004, the number of hours during which restrictions were in place for private vehicles was extended to three hours in both the morning and evening. Finally, in 2009, the number of hours for private vehicles was extended to 14 hours per day, starting at 6 AM. Bonilla (2016) uses hourly data along with a regression discontinuity approach similar to Davis's (2008) to analyze the effects of the first two phases (1998–2004) and last two phases (2004–2009) of the Bogotá program on concentrations of carbon monoxide (a pollutant primarily emitted by mobile sources), gasoline consumption, and vehicle sales and registrations. He is unable to discern an effect of either set of phases on air quality or vehicle use. However, he finds some evidence that the latter two phases of the program actually led to a perverse increase in fuel consumption, vehicle ownership, and air pollution in morning peak hours.

Zhang et al. (2017) use a similar empirical design to examine the effects of all four phases of the Bogotá program on seven air pollutants (carbon monoxide, PM10, three types of nitrogen oxides, ozone, and sulfur dioxide). They find that, in general, the program's different versions have not led to significant overall improvements in air quality. More specifically, they find that the program's effects vary, increasing some pollutants and reducing others, partly as a result of atmospheric chemistry.

4.2.1.4. Quito and Santiago. Carrillo et al. (2016) examine Quito's 2010 Pico y Placa (PyP) program, which restricts driving during peak hours in the central part of the city. They use hourly data along with a triple differences design that takes advantage of both temporal and spatial variation in the policy (which applies to only part of the city). They find that the program has reduced carbon monoxide pollution by 9–11% during peak traffic hours. They speculate that this

success is attributable to vigorous enforcement, the availability of taxis and public transportation, the high cost of purchasing additional vehicles, and uncertainty about whether the PyP program will be continued, which makes drivers reluctant to invest heavily in adapting to it.

Finally, de Grange & Troncoso (2011) examine the effects of Santiago's driving restriction program. Since the late 1980s, this program has prohibited driving vehicles without catalytic converters one day a week during morning rush hours in the autumn and winter. Since the mid-1990s, a more stringent version of the program was implemented: It applies to all vehicles on environmental episode days, when air pollution is predicted to exceed certain thresholds (see Section 4.1.2). De Grange & Troncoso use hourly data along with regression discontinuity models to examine the effects of the original and additional programs on automobile, metro, and bus trips. They find that the original restrictions have not affected the use of private vehicles. However, the additional restrictions have reduced private vehicle use by 6% and increased metro use by 3%.

4.2.2. Other regulations on vehicular emissions. Vehicular emissions standards are common in developing countries. Oliva (2015) examines testing for compliance with such standards in Mexico City, focusing on a common corrupt practice: bribing testing center technicians to use emissions results from clean "donor cars." She identifies test centers that engage in this practice from telltale serial correlation in their emissions test results when they use the same vehicle for consecutive tests. Then, using data from "clean" test centers only, she estimates the fair probability of vehicles passing the test conditional on their observed characteristics. Finally, she estimates a structural model of car owners' testing decisions. Her results indicate that roughly 10% of car owners cheat on emissions tests and that eliminating such cheating would significantly reduce vehicular emissions. Although the study does not directly test for it, it clearly bears on the effectiveness of vehicular emissions standards.

Finally, Kathuria (2002) examines a suite of more than 20 CAC regulations aimed at reducing vehicular emissions in Delhi, including conversion of all commercial vehicles to compressed natural gas, phasing out older commercial vehicles, and ratcheting up emissions standards. The regulations were implemented between 1998 and 2001. To identify the effect of these policies on particulate air pollution and nitrogen oxides, he uses daily 1999–2001 air quality data along with simple event study regression models. He is unable to discern an effect of any of these policies, a finding he attributes to the rapid growth in new vehicle registrations during the study period.

5. MARKET-BASED INSTRUMENTS

Our discussion of market-based instruments focuses on emissions fees and tradable permits. Both require environmental regulators to check compliance and sanction violators, and thus their efficacy in developing countries is open to question. We leave aside environmental taxes (taxes on inputs and outputs associated with pollution), which in general do not require such regulatory inputs. In theory, both emissions fees and tradable permits should have an unambiguous effect in reducing emissions. However, in developing countries, the actual effects are unclear because of tax evasion (Liu 2014), the informal economy (Bento et al. 2017), and as just noted, limited monitoring and enforcement (Blackman 2009, Blackman & Harrington 2000).

Although a number of articles examine various aspects of MBIs in developing countries, including their advantages and disadvantages relative to CAC (Blackman & Harrington 2000, Caffera 2010), evidence on their actual effectiveness is thin—significantly thinner than the evidence on CAC. We were able to find only eight studies that met our criteria for inclusion (**Table 1**). These studies focus on emissions fees in China and tradable permits in Santiago. Overall, the findings are mixed (**Table 2**). Although five of the six studies of Chinese emissions find at least some benefit, neither of the two studies of tradable permits in Santiago finds that they reduced pollution.

5.1. China's Pollution Levy System

We found six studies that examine China's pollution levy system, the largest set of studies focusing on MBI regulation.

5.1.1. Overview. China's pollution levy system is a pillar of the country's environmental regulatory system and has been extensively studied. Rolled out nationally in 1982 after three years of local experimentation, the system regulates 29 water pollutants and 22 air pollutants, as well as solid waste, radioactive waste, and noise. The formulas used to calculate levies have evolved over time.[2] There have been at least three important changes. First, before 1993, levies were assessed only for discharges that exceeded CAC emissions standards; since 1993, all discharges have been regulated. Second, before 2003, polluters were required to pay only for the pollutant associated with the greatest total levy; since 2003, polluters have been required to pay for the three pollutants with the greatest total levy. Finally, before 1995, much of the levies could be rebated to polluters to subsidize investments in pollution reduction equipment; since then, rebates for abatement investments have been converted to loans.

A few researchers have concluded that the peculiarities of the levy system's design have dampened abatement incentives. For example, Lin (2013) argues that because under the current system, plants pay levies only on the three pollutants with the greatest total levy, they have no incentives to abate other pollutants. He also observes that for water pollutants, marginal levy rates are reduced above certain thresholds, which diminishes abatement incentives above those thresholds. In addition, Blackman & Harrington (2000) point out that, because of the wide latitude Chinese firms have in accounting, they may get back some of their levy payments through rebates, whether or not they have invested in pollution reduction equipment. The net effect is to reduce levy rates, again weakening the system's abatement incentives. These design issues, along with the monitoring and enforcement constraints highlighted in the Introduction, imply that rigorous evaluations are needed to assess whether China's pollution levy system actually has environmental benefits.

Probably the greatest challenge in conducting such evaluations is finding reliable data. In China, plant-level environmental performance data are only sporadically available and are not published by the government. Many published articles use plant-level data obtained from national or local environmental protection bureaus (EPBs). As a result, the geographic and temporal scope of these studies is limited. Moreover, the levy system has relied on self-reporting: Polluters report their emissions, and regulators inspect and verify the reports. The accuracy of self-reports is questionable.

5.1.2. Chinese plants' responses to regulatory stringency. Research on the efficacy of the Chinese pollution levy system typically exploits variation in the stringency of the levy system across plants. There are two main sources of such variation (Wang & Wheeler 2005). First, emissions standards are set jointly by the central and provincial governments. As a result, two otherwise identical plants located in different provinces can be subject to different levies. Second, inspection and levy collection are largely decentralized and the responsibility of local EPBs. Therefore, even aside from the heterogeneity just noted, the number of inspections and levy rates can vary significantly across plants.

A common methodological challenge in assessing the effectiveness of Chinese pollution levies is the codetermination of regulatory stringency and plant behavior: Plants change their environmental performance as a result of increased regulatory stringency, but policy makers may also

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[2]See Lin (2013) and Wang & Wheeler (2005) for detailed formulas.

adapt the stringency of regulations (levy rates, inspections) to the environmental performance of regulated plants. To overcome this challenge, some researchers have used a simultaneous equations approach (Jiang & McKibbin 2002, Wang & Wheeler 2005, Wang et al. 2003), and others have used instrumental variables to tease out an exogenous portion of variation (Dasgupta et al. 2001, Jin & Lin 2014, Lin 2013, Wang 2002).

Most studies assessing the Chinese levy system find that higher levy rates lead to improvements in environmental performance. Using cross-sectional data on 891 of China's top water polluters in 1993, Wang (2002) finds that investments in pollution abatement facilities and expenditures on operating those facilities responded strongly to effective levy rates, defined as the levy actually paid for pollution per unit of emissions. He instruments for the effective levy rate using region-level socioeconomic and demographic variables, such as income, education, population density, and environmental complaints. However, it is not clear that these region-level variables do not directly affect plant-level investments and operating expenditures.

Using 1993 cross-sectional state EPB data on 3,000 large air and water polluters, Wang & Wheeler (2005) find that water pollution emissions declined by 1% and air pollution emissions by 0.65% for each 1% increase in the effective levy rate, suggesting that pollution levies generate a strong deterrent effect. The number of regulators per plant and complaints per capita are used to instrument for the effective levy rate. Again, it is not clear that these variables do not directly affect outcomes.

Jiang & McKibbin (2002) develop a structural model of equilibrium pollution using province-level panel data on emissions of waste water, waste gas, and solid waste between 1992 and 1996. They find that pollution intensity was highly responsive to the levy rate.

Jin & Lin (2014) examine the relationships between the effective levy rate, technological efficiency, and pollution intensity using province-level panel data from 1992 to 2008. They find that the effective levy rate significantly reduced pollution intensity.

Using panel data on individual industrial polluters in Zhenjiang between 1993 and 1997, Dasgupta et al. (2001) analyze the effect on total suspended solids and COD water pollution and total suspended particulates air pollution of both pollution levies and regulatory inspections. Time trends are used to instrument for the number of inspections, a method that relies on the assumption that factors affecting emissions are uncorrelated with time. The authors find that, although the number of inspections reduced emissions, the pollution levy had a statistically insignificant effect.

Finally, Lin (2013) uses quarterly plant-level panel data from the food, chemical, paper, and medicine sectors in an unidentified municipality to analyze how regulatory inspections aimed at enforcing pollution levies affected COD water pollution. He uses plausibly exogenous variation in rainfall to instrument for the number of inspections while carefully distinguishing between actual emissions and those self-reported by plants under the fee discharge system. He finds that inspections caused an increase in self-reported emissions. Acknowledging the institutional uncertainties outlined above, Lin does not come to a conclusion about the effect on real emissions. His results are opposite those of Dasgupta et al. (2001), a contrast that points to rich opportunities for further research.

5.2. Santiago's Tradable Air Pollution Permits Program

Established in 1997, Santiago's air pollution permit trading program initially focused on particulate matter. Later, its scope was expanded to include nitrous oxides and other pollutants. After the program was implemented, air emissions dropped sharply in Santiago, which has led advocates to

assert that the program was responsible. Coria & Sterner (2009) provide detailed background and document the reduction in emissions in the years following the start of the program.

Early studies of the Chilean permit trading program tended to focus on practical implementation issues. Montero et al. (2002) document a failure to reconcile permits and emissions. They also point out that grandfathered permits created incentives for polluters to overstate their initial emissions, which led to a significant overallocation of permits. Coria et al. (2010) conduct interviews of firms that are subject to the program and finds that firms complained most about policy implementation—specifically, a lack of transparency, plus uncertainty about the rights associated with permits, the schedule for monitoring, and the penalties for noncompliance. Palacios & Chávez (2005) use firm-level data along with a binary choice model to identify the determinants of the compliance decisions. They conclude that the firms' characteristics affected their compliance decisions.

Only two articles, both based on plant-level data, rigorously evaluate the program's efficacy. Using cross-sectional data, Montero et al. (2002) find that fuel switching—from dirty fuels to relatively clean natural gas—was largely responsible for the reduction in air emissions following rollout of the permit trading program, but the program itself did not encourage that switch. Coria (2009) uses panel data along with a hazard model to compare the importance of the permit trading system with energy prices in inducing the switch. She finds that the effect of the tradable permit system was not significant.

6. DISCUSSION

6.1. Efficacy

Our review of evidence on CAC and MBI regulations in developing countries clearly shows that they can generate environmental benefits. Of the 32 CAC studies we reviewed, 24 (75%) find evidence of benefits. Of the 8 MBI studies, 5 (63%) find evidence of benefits. Overall, of the 40 studies of both types of regulation, 29 (73%) find evidence of benefits (**Table 2**).

However, those statistics do not indicate that CAC and MBI regulations are likely to have benefits in developing countries; rather, they almost certainly overstate effectiveness, for two reasons. First, the studies we reviewed are drawn from a small and decidedly nonrepresentative sample of developing countries. By necessity, the rigorous quantitative studies on which we have focused examine countries for which the requisite data are available. One would expect these countries to have relatively strong regulatory and data collection institutions, characteristics that are likely strongly correlated with the effectiveness of CAC regulations. An accounting of the countries covered in our review bears out that hypothesis. The 32 CAC studies focus on only seven countries, Brazil, Chile, China, Colombia, Ecuador, India, and Mexico (**Table 2**); and the 8 MBI studies focus on only two countries, Chile and China. In 2017, all of these countries except India were classified by the World Bank as upper-middle-income or high-income countries. Moreover, 32 of these studies (80%) look at only three countries, China (18), Mexico (8), and Chile (6). Second, leaving aside selection bias for certain types of developing countries, among studies focusing on these countries, publication bias is likely to have selected for those showing that regulation was effective. In general, empirical economic studies with positive results are more likely to be published (Franco et al. 2014, Rothstein et al. 2006). Relatedly, researchers have strong incentives to highlight positive results instead of negative ones (Brodeur et al. 2016).

6.2. Efficacy by Type

The evidence we have reviewed sheds light on the efficacy of certain types of CAC and MBI regulations. We have the most rigorous evidence—10 studies—on license plate–based driving

restrictions policies. The studies indicate that the permanent driving restrictions programs in Bogotá, Mexico City, and Santiago (leaving aside the temporary environmental episode restrictions in Santiago) had no discernible benefits, had only fleeting ones, or actually exacerbated the problems they aimed to solve. In contrast, the programs in Beijing and Quito succeeded in reducing air pollution and/or traffic congestion. Overall, 6 of the 10 studies demonstrate some benefit, if only temporary. Note, however, that even though this set of studies suggests that driving restrictions policies can have significant benefits, they do not necessarily imply that these programs are cost-effective. Emerging evidence on the costs of driving restrictions suggest that they impose very significant costs on drivers (Blackman et al. 2018a,b; Gallego et al. 2013a).

We also have a critical mass of rigorous studies—six—on China's pollution levy program. They suggest that the levy system has improved plants' environmental performance. Four of five studies find that higher levy rates led to improved environmental performance. Among the two studies focusing on the effects of inspections, one finds that inspections reduced emissions, and one finds they increased reported emissions.

Aside from the evidence on driving restrictions and pollution levies, two studies suggest that Santiago's episodic CAC air pollution regulations, implemented on severe air pollution days, had significant benefits. Finally, two studies suggest that Beijing's efforts to improve air quality during the 2008 Olympic Games, using a suite of CAC policies, were effective.

6.3. Causal Mechanisms

The evidence we have reviewed provides some hints about causal mechanisms that drive effectiveness of CAC and MBI regulations. Again, we have the most evidence on license plate–based driving restrictions. Although 10 studies are too small a sample from which to draw reliable inferences about causal mechanisms, the authors who documented successful programs in Beijing and Quito have speculated about the factors correlated with effectiveness (Carrillo et al. 2016, Viard & Fu 2015). These include stringent program enforcement, the high cost and limited availability of vehicles, the low cost and high quality of public transportation, and in the case of Quito, uncertainty about the longevity of restrictions. Two studies suggest that in developing countries, corruption plays a major role in blunting the effect of CAC regulation, and that interventions aimed at checking corruption, such as auditing the auditors, may enhance efficacy (Duflo et al. 2013, Oliva 2015). Finally, two studies hint that tying administrative promotions and job security to regulatory enforcement can enhance efficacy (Jin & Lin 2014, Kahn et al. 2015).

7. FUTURE RESEARCH

Although rigorous quantitative evaluations of CAC and MBI regulations in developing countries are being published more and more frequently—an encouraging trend—the evidence base remains quite thin overall. Several gaps need to be filled. Some gaps correspond to the issues discussed above. First, studies are needed on countries other than upper-middle-income and high-income countries such as China, Mexico, and Chile. Although data availability is a limiting factor, there surely are middle- and low-income countries where studies are feasible, perhaps using remotely sensed data on air and water quality (Donaldson & Storeygard 2016).

Second, even for the countries where we have evidence, such as China, Mexico, and Chile, more studies of underrepresented regions are needed. For example, most of the existing evidence on China's pollution levy system is based on data provided by municipalities in China's eastern provinces. Studies on other parts of China would paint a more complete picture of the system.

Third, further evidence is needed on MBI regulations in developing countries. We could find only eight rigorous studies that met our criteria, and these studies focus on only two MBI

policies—pollution levies in China and tradable permits in Santiago. Although the evidence from China is certainly encouraging, the evidence base as a whole does not enable us to generalize about the efficacy of MBIs in developing countries. Given the limited number of studies, it is not possible to disentangle the effects of place-based factors from those related to the policy instruments.

Fourth, further evidence is needed on specific types of CAC regulations. At present, we have a critical mass of studies on only license plate–based driving restrictions, emissions fees, and a few other policies. Fifth, outcome variables such as health or environmental quality are rare; these may be of greater policy interest than emissions. Sixth, research with alternative identification strategies, such as regression discontinuity design or propensity-score matching, might help researchers reconcile conflicting conclusions in the current literature on Chinese pollution levies. Seventh, studies are needed that identify causal mechanisms associated with successful CAC and MBI policies.

Finally, additional research on the costs of CAC and MBI policies in developing countries is needed. Although our review has focused on studies of efficacy, not studies of costs, it is safe to say that the latter are at least as scarce. Notwithstanding the thin evidence base, researchers have long speculated about the relative cost-effectiveness of CAC and MBI policies in developing countries. Proponents have suggested that MBI policies are likely to be more cost-effective because, as textbook treatments tell us, they incentivize shifting the burden of abatement from polluters with high abatement costs to those with low costs (Panayotou 1993). However, others have pointed out that such cost savings may be difficult to realize in the challenging institutional and economic environments found in many developing countries (Bell & Russell 2002, Blackman & Harrington 2000). Additional evidence on the costs of CAC and MBI policies, as well as on their efficacy, is needed to advance this debate.

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