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Voluntary Regulations and Innovation: The Case of ISO 14001

Governments enact environmental regulations to compel firms to internalize pollution externalities. Critics contend that regulations encourage technological lock-ins and stifle innovation. Challenging this view, the Porter-Linde hypothesis suggests that appropriately designed regulations can spur innovation because (1) pollution reflects resource waste; (2) regulations focus firms' attention on waste; and (3) with regulation-induced focus, firms are incentivized to innovate to reduce waste. This article explores the regulation–innovation linkage in the context of voluntary regulations. The authors focus on ISO 14001, the most widely adopted voluntary environmental program in the world. Examining a panel of 79 countries for the period 1996–2009, they find that country-level ISO 14001 participation is a significant predictor of a country's environmental patent applications, a standard proxy for innovation activity. The policy implication is that public managers should consider voluntary regulation's second-order effects on innovation, beyond their first-order effects on pollution and regulatory compliance.

Can voluntary environmental regulations promote environmental innovation?[1] Traditional regulations, sometimes called command and control, specify the maximum pollution that regulatees can emit or discharge and the technologies they need to install for pollution control. This regulatory approach has worked well in many ways. Compared to the 1960s, air and water pollution levels have come down significantly. Critics of command and control, however, contend that these regulations have imposed heavy costs on both the regulatees and the regulators. Since the 1980s, there has been an active debate about whether the allegedly high-cost regulatory environment is encouraging the relocation of pollution-intensive industries from developed countries to lightly regulated developing countries (Cao and Prakash 2010; Jaffe et al. 1995). More importantly, from our point of view, command and control regulations have been accused of stifling innovation and creating long-term inefficiencies. Critics contend that high compliance costs hurt regulatees' profitability and reduce their ability to undertake research and development (R&D) (Gray and Shadbegian 1998; Palmer, Oates, and Portney 1995), thereby leading to technological lock-ins (Comin and Hobijn 2009).

In the context of the regulatory efficiency debate, Porter and van der Linde (1995) introduce a novel idea. They suggest that pollution should be viewed as a resource waste issue, not necessarily as a property rights or an externality issue (Coase 1960). From a firm's perspective, policies that reduce resource waste should also improve profits. Their message to firms as well as to public managers is that appropriate regulations can direct managerial attention to resource waste and thereby encourage firms to invest in innovations that can reduce waste. Porter and van der Linde (1995) caution, however, that only some types of regulations promote innovation. Regulations that lead firms to identify waste must also give them the autonomy to change their production processes and internal management systems to reduce waste. For them, regulations must not specify technologies. The key idea is that firms should be allowed to experiment with new ways that economize on resources. Thus, appropriate regulations create a "double dividend": more profits and less pollution.

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This is the first article to examine the Porter-Linde hypothesis in the context of voluntary environmental regulations. Voluntary programs are regarded by public managers as important tools for New Public Management (Kettl 2002) that can mitigate the "regulation dilemma" for governments facing budgetary constraints (Potoski and Prakash 2004). They provide valuable information that allows regulators to sort firms based on their commitment to regulatory compliance. Consequently, regulators can focus their monitoring and enforcement resources on firms

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that are less likely to comply with the law (Toffel and Short 2011). Public managers have supported and even sponsored voluntary programs. For instance, the U.S. Environmental Protection Agency (EPA) has been at the forefront of the voluntary programs movement, having sponsored more than 87 voluntary programs to date (Carmin, Darnall, and Mil-Homens 2003; Coglianese and Nash 2001; Morgenstern and Pizer 2007).[2]

Public managers will find that this article moves the discussion on voluntary regulations in a new direction. While much of the debate has focused on conditions under which voluntary programs lead their participants to reduce pollution and improve compliance with public law, our study suggests that public managers should also consider these programs' second-order effects, especially in light of the regulation–innovation debate. We suggest that voluntary regulatory programs can also incorporate the innovation-inducing mechanisms proposed by Porter and van de Linde. Voluntary programs can spur innovation if they are designed to improve participants' internal management systems, allowing boundedly rational managers to systemically identify areas of resource waste. Further, programs must not bind firms to specific technological solutions. With this type of program design, voluntary programs can create incentives for firms to innovate. Viewed in this way, appropriately designed voluntary programs can become useful tools for public managers because they support both the environmental and the economic goals that public managers seek to pursue.

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Empirically, we focus on the most widely adopted voluntary environmental program in the world, ISO 14001. Established by the Geneva-based International Organization for Standardization (ISO) in 1995, ISO 14001 prescribes the broad principles for firms' internal environmental management. Firms participating in ISO 14001 must establish a written environmental policy, document their internal management systems, specify quantifiable environmental targets, regularly review their progress, and designate a top manager to oversee implementation of these commitments. Further, it requires that an accredited third-party auditor periodically confirm participants' compliance with program requirements. ISO 14001's philosophy closely follows Porter and van der Linde's logic: if appropriate management systems are in place to identify areas for improvement, desired outcomes will follow.

Our analysis of a panel of 79 countries for the period 1996–2009 reveals that, all else being equal, country-level ISO 14001 participation is a significant predictor of country-level environmental patent applications, a standard proxy for innovation activity. Our results hold even when we include a host of control variables and use modeling strategies that respond to concerns about endogeneity and selection bias.

The article is organized in six sections. In the second section, we provide a brief survey of the regulation and innovation literature. In the third section, we develop our hypothesis in the context of voluntary regulations and describe the key analytic features of ISO 14001. We introduce our data and methods in the fourth section and present the findings of our statistical analyses, along with robustness checks, in the fifth section. We conclude in the sixth section.

Regulation–Innovation Debate

In theory, environmental regulations are designed to induce firms to internalize the costs of externalities such as pollution (Pigou 1960; but see Coase 1960; Ostrom 1990). Because profit-seeking firms have few incentives to correct these market failures on their own, governments compel them to do so through regulations, which tend to specify the permissible pollution levels and stipulate the pollution control technologies that regulatees need to install. Hence the term *command and control:* regulations *command* regulatees how much pollution to reduce and *control* how they do it by specifying technologies (Cole and Grossman 1999).

Critics of command and control often focus on the *static efficiency* implications of regulation, that is, the cost and benefit analysis estimating compliance and enforcement costs in relation to environmental and public health benefits. They contend that command and control imposes high costs on both the regulators and the regulatees in relation to the benefits. Because compliance costs are high, regulatees are often discouraged from fully complying, which, in turn, increases enforcement costs imposed on the regulator's side (Ackerman and Stewart 1985; Fiorino 1999).[3] This creates dilemmas for regulators whose budgetary resources seem insufficient to fulfill their regulatory mandates.

What might be the way forward? While the literature is not conclusive, there is some evidence that some voluntary programs can further the traditional regulatory objectives of pollution reduction and regulatory compliance.[4] Russo (2002) finds that ISO 14001 certification is associated with decreased air pollutant emissions in U.S. electronics facilities. Prakash and Potoski (2006b) find that ISO 14001 adoption is associated with superior regulatory compliance as well as air pollution reduction in the United States. Outside the United States, Arimura, Hibiki, and Katayama (2008) provide evidence suggesting that ISO 14001 participation is associated with pollution reduction in Japan, and Dasgupta, Hettige, and Wheeler (2000) report that ISO 14001 adopters in Mexico's food, chemical, nonmetallic minerals, and metals industries show superior compliance with environmental regulations. Thus, public managers can be reasonably confident that certain voluntary programs have the potential to mitigate the regulatory dilemma and improve regulatory efficiency.

We suggest that the usefulness of voluntary regulation for public managers goes beyond mitigating the regulatory dilemma and achieving the traditional regulatory objectives. We focus on the *dynamic efficiency* (Bauer and Bohlin 2008) implications of voluntary regulation, which incorporate the possibility of "changing the production function in profitable directions, making use of newly disclosed opportunities, be they opportunities for improving the production process or developing and producing new products" (Klein 1984, 46–50). Command and control regulations have been criticized on the grounds that they create dynamic inefficiencies by forcing firms to focus resources on compliance and not on innovation (Gray and Shadbegian 1998; Palmer, Oates, and Portney 1995). Further, the technology-forcing aspects of command and control lead to technological lock-ins, as regulatees who have invested in specific technologies have fewer incentives to innovate thereafter. Indeed, to protect their rents, regulated firms often lobby for the continuation of existing technologies that serve as barriers to entry (Comin and Hobijn 2009).

Porter and van der Linde (1995) seek to recast the debate on benefits and costs of environmental regulations by focusing attention on the positive implications of regulation for dynamic efficiency. For them, pollution represents resource waste. Regulations can encourage firms to develop innovative policies and products to reduce the resource waste. If uncovering resource waste can improve profits through innovation, why do profit-maximizing firms not do so on a regular basis? Why do they need regulation? While recognizing that firms seek profits, Porter and van der Linde (1995) emphasize that managers are boundedly rational: "intendedly rational but only limitedly so" (Simon 1957, xxiv). Firms work with limited information about profit opportunities, even when the opportunities lie within the firm. Porter and van der Linde note,

> The possibility that regulation might act as a spur to innovation arises because the world does not fit the Panglossian belief that firms always make optimal choices . . . the actual process of dynamic competition is characterized by changing technological opportunities coupled with highly incomplete information, organizational inertia and control problems reflecting the difficulty of aligning individual, group and corporate incentives. Companies have numerous avenues for technological improvement, and limited attention. (1995, 99)

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How do regulations induce innovation? Porter and van der Linde implicitly identify two mechanisms: an economic one and an organizational politics one. The economic mechanism is rooted in the aforementioned notion of bounded rationality, whereby firms are not aware of resource waste and hence do not make efforts to innovate in this area. Regulatory interventions focus the attention of boundedly rational managers on areas of resource waste. Per the analogy that Porter and van der Linde employ, it is like picking up the dollar bills lying on the road that nobody has bothered to pick up. This may involve simple issues such as identifying packaging waste or unnecessary packaging, which can be eliminated without compromising the quality of the product or its shelf life. Regulations such as recycling laws may involve more complex issues, forcing firms to innovate to reuse their materials or use less of disposable components. Regulations may also touch on truly complex issues, which require fundamentally reformulating products or reengineering production processes to remove, say, toxic components (Antweiler and Harrison 2003; Helland and Whitford 2003; Kraft, Stephan, and Abel 2011).

Regulatory interventions focus the attention of boundedly rational managers on areas of resource waste.

The organizational politics mechanism rests on the notion that firms are "political coalitions" (Cyert and March 1963) that tend to favor the status quo. Attempts to usher in changes confront "organizational inertia" (Hannan and Freeman 1984). Change agents may need external support to justify their inquiries, identify resource waste, or experiment with new technologies and processes. Regulatory pressure can encourage firms to examine their internal operations and seek ways to work more efficiently, just as external competition and consumer and stakeholder pressure do (Delmas and Toffel 2008; Prakash 2000). These pressures create organizational and technological "turbulence" (Candi, van den Ende, and Gemser 2013; Gryskiewicz 1999) that helps upset the status quo. Regulatory pressures can also ameliorate incentive problems between owners and managers and induce communication inside the firm (Bonato and Schmutzler 2000, 525).

Porter and van der Linde (1995), however, identify an important scope condition on their argument: only regulations with specific characteristics can spur innovations. Most importantly, regulations should not be technology forcing. Instead, regulations should encourage firms to examine their internal processes and production technologies to identify resource inefficiencies. Porter and van de Linde note,

> Past regulations have often prescribed particular remediation technologies . . . But legislating as if one particular technology is always the "best" almost guarantees that innovation will not occur. Regulations should encourage product and process changes to better utilize resources and avoid pollution early, rather than mandating end-of-pipe or secondary treatment, which is almost always more costly. (1995, 100–111)

A number of studies have empirically tested the Porter-Linde hypothesis. Lanjouw and Mody's (1996) country-level analysis finds a positive association between pollution abatement and control expenditures (PACE, as a proxy for regulatory stringency) and environmental patent activities (as a proxy for innovation) in United States, Japan, and Germany. Haščič et al.'s (2009) country-level study finds a positive link between the stringency of car emission standards and patents in automotive emission technologies in the OECD (Organisation for Economic Co-operation and Development) countries. Johnstone et al.'s (2012) country-level study of 77 countries uses perceived regulatory stringency revealed in opinion surveys as a proxy for regulatory pressure and finds a positive association between regulatory pressure and environmental patent activities.[5] Studies conducted at the industry level present more mixed findings. Jaffe and Palmer (1997) find that the PACE expenditures in the U.S. industries have a positive association with their private R&D expenditures yet have no effect on industry-level environmental patent activities. Brunnermeier and Cohen's (2003) study on U.S. industries examines the number of inspection visits as a proxy for regulatory stringency and finds no effect of such visits on industry-level environmental patent activities.

To the best of our knowledge, this is the first study to systematically examine the Porter-Linde hypothesis in the context of voluntary regulations in a cross-country panel setting.

Innovation-Friendly Regulatory Design: The Case of ISO 14001

Porter and van der Linde identify two important criteria: (1) regulations should be stringent yet (2) should not mandate specific technologies. We argue that ISO 14001 is a highly appropriate case to test the Porter-Linde hypothesis.

Regarding the flexibility criteria, ISO 14001 does not mandate any specific technology. Instead, it requires firms to adopt environmental management systems that will be audited by accredited third-party auditors. The rationale for focusing on management systems instead of production technologies is that if appropriate processes are in place, desired outcomes will follow. In the process of establishing these management systems, firms create systematic knowledge and documentation of their internal systems and processes. This documentation allows boundedly rational managers to identify new ways and areas for environmental improvements. It is this sort of internal focus on internal processes that allows firms to spot inefficiencies and resource waste (Darnall and Kim 2012; Prakash and Potoski 2006b).

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When it comes to the stringency criteria, there are two aspects of this. The first aspect concerns the standards that are imposed on participating firms that obligate them to invest in environmental stewardship. The second aspect concerns the mechanisms for ensuring that firms honor their environmental obligations. On the first account, ISO 14001 might not seem to be a stringent program, as it does not impose any quantified standard. Yet ISO 14001 requires firms to adopt management systems that are quite extensive, requiring substantial investments in personnel, training, and, most critically, careful documentation and evaluation of their environmental operations. As the literature suggests, the cost of adopting and maintaining these environmental management systems can be sizable—from $25,000 to $100,000 per facility. The environmental management systems are then assessed by accredited third-party auditors. This is an important feature of ISO 14001 given that prior research suggests that the absence of such monitoring leads firms to shirk on their program obligations (King and Lenox 2000).

ISO 14001 offers other advantages as well because it is the most widely adopted voluntary environmental program with significant uptake across sectors. Thus, we should be able to observe its effect on innovation activities at the level of the national economy without focusing on specific sectors. Importantly, ISO 14001 has witnessed active participation in developing as well as developed countries.[6] This is partly attributable to the fact that ISO membership can serve as an eco-label, or a "symbol of the participating firm's commitment to environmental management systems." ISO adoption can help improve a firm's image by conferring greater "environmental legitimacy" (Bansal and Hunter 2003, 291), even in the context of poor country-level environmental performance. Empirical studies have indeed found some evidence that firms adopt ISO 14001 to appeal to environmentally conscious trading partners (Prakash and Potoski 2006a). Because firms face market-based incentives in addition to extensive third-party auditing, the costs of compliance might not necessarily deter firms from engaging in innovative efforts but rather may encourage them to invest in innovation in expectation of higher exports.

Importantly, it is not necessary that the firms undertake this innovation themselves. Arguably, firms can fund such R&D outside. Indeed, there is a literature suggesting that in some industries such as pharmaceuticals, firms fund R&D that is often undertaken outside the firm (Dushnitsky and Lenox 2005). Universities and research institutions can play an important role in this regard. Schacht notes that cooperation between industry and university and research institutions is "one important mechanism intended to facilitate technological innovation" (2007, 123). While universities and other academic institutions have competencies to undertake research that is integral to certain technological advancements, they often lack the capacities to successfully commercialize them, that is, to translate their expertise into "products and processes that can be sold in the marketplace" (Schacht 2007, 123). Often, the patent titles to inventions made by contractors such as universities are vested in the contractors, who would then license to industry, where the technology can be deployed. Indeed, such a process can be aided by government policy; the Bayh-Dole Act of 1980 allowed U.S. universities and other recognized institutions to retain patents of inventions generated with the help of federal resources, which empowered the universities to connect with local industries and commercialize the new technologies.

Thus, counting only the number of patent titles that belong to a specific firm or industry would underestimate this kind of broader spillover effect on innovation created by ISO 14001. This is consistent with the findings from existing country-level studies that employ patent counts as a proxy for innovation activities (Haščič et al. 2009; Johnstone et al. 2012). Therefore, our claim is that an increase in ISO participation of domestic firms would induce innovation activity that can spill over outside of the participating firms to broader domestic economy. Based on the above discussion, we propose the following hypothesis:

> **Hypothesis:** ISO 14001 participation will promote innovation activity in the realm of environmental management technologies.

Research Design

We test our hypothesis using an unbalanced panel of 79 countries over the time period 1996–2009. Our key explanatory variable is the annual ISO 14001 participation levels (logged) observed at the country level. Our dependent variable is the number of international patent applications in environmental technology, based on fractional counting (logged).[7] Consistent with prior literature (Johnstone et al. 2012), we focus specifically on patents classified as "general environmental management" in the OECD's patent database. Patents included in this category are those concerning air pollution abatement (specifically from stationary point sources), water pollution abatement, waste management (such as solid waste collection and recycling), soil remediation, and environmental monitoring.[8] These are the patents specific to technologies that allow firms to reduce environmental externalities created in the production processes, which corresponds well with the goal of ISO 14001.

Patent applications provide an appropriate proxy for innovation activities, for four reasons. First, because international patent applications are scrutinized under a standardized review process, we can compare innovation efforts among countries that might have different domestic standards for recognizing innovation. Second, while one could use expenditure data on R&D or on human capital as proxies for innovation, this is problematic because this measures the inputs into the innovation process. Patent applications, as the outcome of innovation process, are therefore a better measure to assess how ISO 14001 might influence innovation. Third, we expect ISO 14001 to influence environmental management innovations only. However, national-level data on human capital and R&D focused on environmental technologies only are not available for a significant slate of countries, especially those in the developing world. In contrast, data on patent applications for environmental technologies are readily available. This allows us to explore the effect of voluntary environmental regulation on environmental management innovation without confounding it with innovative efforts in other areas, such as sales and marketing. Fourth, while ISO 14001 adoption creates a demand for innovation at the firm level to begin with, it is not necessary that the firms themselves undertake this innovation activity. A national-level count of environmental-technology-related patents allows us to pick up the ISO 14001–induced innovation activity that has spilled over outside the firm.

We include a set of control variables that might influence levels of environmental innovation. First of all, technology spillover from other areas can drive environmental innovation. Therefore, we control for the number of other patent applications, excluding those classified as general environmental management.[9] This measure also serves as a proxy for the general level of international patent activity. We also control for levels of economic development (gross domestic product [GDP] per capita and its squared term). This is a proxy for the quality of the innovation infrastructure as well as the human resources available for environmental innovation, which are important supply-side drivers of innovations. This can be viewed as a proxy for domestic environmental stringency, given that richer countries have both more capacity and face citizen demands to protect the environment.

We control for the level of economic openness, measured in terms of export and foreign direct investment (FDI) inflows (as a percentage of GDP). Open economies have incentives to invest in innovation to remain competitive in global markets. Further, international economic interactions can initiate diffusion and isomorphic processes through which these economies learn from their competitors abroad (Guler, Guillén, and Macpherson 2002). We also include (logged) GDP (in constant 2005 U.S. dollars) to control for the size of the economy. Innovation activities might benefit from economies of scale, which provide an advantage to larger economies.[10]

Our model also controls for political and institutional factors that can influence innovation levels. As Popp (2004) notes, receiving the monopoly rights inferred by a patent requires an inventor to publicly disclose the invention. Inventors from countries where intellectual properties are not well defined might tend to keep an invention secret rather than make this disclosure. If returns from innovations can be protected by the rule of law, firms are more likely to devote resources to innovation efforts. Hence, we control for the level of democracy (Polity IV)[11] and property rights protection (Heritage Foundation).[12] These political institutional variables are expected to be correlated with the quality of public regulatory governance in a country. The descriptive statistics for the variables included can be found in the appendix.

Finally, we include country fixed effects to control for country-specific and time-invariant heterogeneity that can influence a country's level of environmental innovation. For instance, although it is difficult to find a direct indicator measuring the quality of public environmental regulatory governance across a large number of countries, the fixed effects are expected to capture the unmeasured, time-invariant differences in this regard.[13]

Our main model specification is expressed as follows:

$$\text{EnvironmentPatents}_{it} = \gamma_1 \text{ISO}_{it-1} + \gamma_2 \text{otherPatents}_{i,t-1} + X_{it-1}\beta + \alpha_i + \varepsilon_{it} \qquad (1)$$

where γ captures the effects of the key explanatory and control variables and β represents a vector of parameter estimates for the additional control variables, denoted *X*. In addition, α captures the country fixed effects, and ε_{it} is the error term. We lag key explanatory and control variables by one year to take into account the expected delay between a change in the independent variable and the response in the dependent variable. Because patent applications are measured using the fractional counting method (as explained earlier), we choose to fit them with a linear model instead of count models. Both environmental patent count and ISO participation are logged. Consequently, ISO 14001 coefficient estimates can be interpreted in terms of elasticity: percentage change in environmental innovations in response to percentage change in ISO 14001 adoption.

Our analysis proceeds as follows: We begin with the basic model specification, which includes only ISO membership, the number of other patents, and country fixed effects (model 1). Then we estimate a specification that includes the full set of control variables discussed earlier, which is considered our main model (model 2). As robustness checks (models 3–6), we add yet additional control variables: R&D expenditure as a percentage of GDP (World Bank), high-tech export dependency as a percentage of total manufacturing exports (World Bank), quality of human capital as reflected in the tertiary education enrollment rate (World Bank), and intergovernmental environmental treaty memberships (Environmental Treaties and Resource Indicators). The covariates are added one by one to keep more observations in the sample. The results are summarized in table 1.

Next, we address concerns about the potential endogeneity of ISO participation using an instrumental variable approach. As an alternative strategy, we also conduct generalized method of moments

(GMM) estimation employing internal instruments only. The results are summarized in table 2 as models 7 and 8. Finally, we fit a selection model to take into account the potential bias induced by those observations with zero ISO participation, which accounts for a little over 10 percent of our sample. Arguably, unmeasured errors in the selection process (i.e., a country being introduced to ISO 14001) might be correlated with the unmeasured errors in the outcome process (i.e., the effect of an increase in ISO participation on environmental innovation). The results from these models are reported in table 3 as model 9.

Table 1 Determinants of Environmental Innovation

	Model 1		Model 2 (Main)		Model 3		Model 4		Model 5		Model 6	
	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)
ISO participation	0.111	0.000	0.096	0.039	0.105	0.018	0.126	0.002	0.125	0.036	0.067	0.048
Other patents	0.171	0.000	0.154	0.008	0.146	0.007	0.219	0.041	0.211	0.007	0.200	0.000
GDP per capita			9.713	0.033	9.036	0.059	9.379	0.179	8.755	0.176	14.507	0.004
GDP per capita^2			–0.621	0.015	–0.611	0.021	–0.752	0.127	–0.709	0.021	–0.852	0.006
Export			0.012	0.497	0.014	0.498	0.022	0.124	0.006	0.720	0.019	0.354
FDI			0.003	0.728	0.007	0.333	–0.002	0.807	0.008	0.437	–0.011	0.288
Democracy			0.002	0.954	0.013	0.789	–0.054	0.357	–0.020	0.776	0.013	0.797
Property rights			–0.000	0.990	0.002	0.866	0.004	0.783	0.008	0.436	–0.001	0.939
Size of economy			1.916	0.456	2.212	0.377	4.396	0.059	4.261	0.135	1.038	0.644
High-tech export					–0.019	0.331						
Tertiary education							–0.006	0.718				
R&D expenditure									0.030	0.866		
Environmental treaty											0.008	0.092
Observation(country)	1,248(96)		990(79)		969(79)		797(76)		768(76)		646(78)	
Maximum years	14		14		14		14		14		10	
Country fixed effects	Yes		Yes		Yes		Yes		Yes		Yes	

Table 2 Dealing with Endogeneity: Instrument Variable Regression and GMM

	Model 7			Model 8	
	2SLS			Two-step System GMM	
	Estimate	Pr(>|*t*|)		Estimate	Pr(>|*z*|)
(Instrumented) ISO participation	0.165	0.009	ISO participation	0.134	0.048
Other patents	0.141	0.024	Other patents	0.619	0.000
GDP per capita	10.239	0.077	GDP per capita	–5.376	0.000
GDP per capita^2	–0.649	0.049	GDP per capita2	0.301	0.000
Export	0.000	0.984	Export	0.009	0.080
FDI	0.009	0.328	FDI	0.007	0.551
Democracy	–0.019	0.647	Democracy	0.063	0.094
Property rights	0.001	0.928	Property rights	0.009	0.310
Size of economy	1.823	0.545	Size of economy	0.732	0.000
Observation(country)	908(79)			894(78)	
Maximum years	13			14	
Country fixed effects	Yes			Yes	
Sargan Test	1.297 (p = .255)		Sargan Test	59.072 (p = .233)	
First stage test for weak instrument	133.637		AR(2)	–0.179 (p = .429)	
Instrumental variables	BTC-ISO and BTC-INGO		GMM instruments	ISO participation (t –2 to t – 4)	

Table 3 Testing for Selection Bias

	Model 9				
	Selection (Probit)			Outcome	
	DV: Any Positive ISO Membership (= 1)			DV: Environmental Patent Count	
	Estimate	Pr(>|*z*|)		Estimate	Pr(>|*t*|)
Bilateral trade context: ISO	0.260	0.037	ISO Participation	0.084	0.100
Total patents	0.028	0.332	Other Patents	0.146	0.109
GDP per capita	3.095	0.149	GDP per capita	3.659	0.699
GDP per capita^2	–0.169	0.174	GDP per capita^2	–0.455	0.329
Export	0.000	0.971	Export	0.012	0.467
FDI	–0.025	0.255	FDI	0.013	0.432
Democracy	0.045	0.004			
Property rights	0.014	0.024			
Size of economy	0.731	0.000	Size of economy	4.622	0.030
			Inverse Mills ratio	0.188	0.772
Observation(No ISO participating firm)	990(111)		Observation	879	
Maximum years	14			14	
Fixed effects	Time			Country	

Results and Findings

Table 1 summarizes results from our null model, which estimates patent application counts based only on the most basic set of covariates (model 1); our main model, which includes all theoretically important control variables discussed earlier (model 2); and robustness checks, which include additional covariates (models 3–6). Along with the coefficient estimates, we report *p*-values based on Driscoll and Kraay's (1998) robust standard errors. The estimates of ISO 14001 are positive and statistically significant across all specifications.

As both ISO 14001 and patent counts are logged, the ISO coefficient can be interpreted as an elasticity measure.[14] The ISO 14001 coefficient in model 2 is 0.096: this suggests that a 1 percent increase in ISO participation leads to about a 0.096 percent increase in environmental patent count, all else being equal. Substantively, this means that an observation at the median level of ISO participation in our sample (i.e., 78 ISO certifications) will have about 130 percent more environmental patents than an otherwise similar observation at the first quartile in terms of ISO participation (i.e., 6 ISO certifications).

When it comes to control variables, nonenvironmental patent activities and level of economic development have significant and positive associations with environmental patent activities. It is noteworthy that membership in intergovernmental environmental treaties weakens, yet does not completely nullify, the effect of ISO participation (model 6). This might suggest that there is some overlap between the influences through intergovernmental treaties regimes and a voluntary, nongovernmental regime such as ISO 14001.

Our finding summarized is robust when patent count and ISO participation count variables are both GDP denominated. Our finding also holds when we use the triadic patent families database—patents filed together at the European Patent Office, U.S. Patent and Trademark Office, and Japan Patent Office—as an alternative measure of our independent variable. See the appendix for the results.

How might we address concerns about endogeneity between environmental innovation and ISO 14001 adoption? If firms that are more capable of environmental innovations self-select themselves to participate in ISO 14001, we might be overestimating the effect of ISO participation on environmental innovation. To evaluate the casual effect of ISO participation, we need to focus on exogenously driven participation in ISO 14001. To address this issue, we estimate an instrumental variable regression. Econometrically, we require an instrument that is sufficiently correlated with ISO 14001 (i.e., relevance criteria) but uncorrelated with the error term in the equation (i.e., the validity of the exclusion restriction). That is, the instrument must not have an effect on environmental innovation except through ISO participation. We estimate two-stage least squares regression (2SLS) employing two external instruments: (1) the weighted average of ISO 14001 participation levels among a country's trade partners, weighted by their share in the exports of this country (bilateral trade context in ISO, or BTC-ISO); and (2) the weighted average of membership in international nongovernmental organizations among a country's trade partners, weighted by their share in the exports of this country (bilateral trade context in INGO, or BTC-INGO).

First, bilateral trade context in ISO (BTC-ISO) participation is a relevant instrument because prior research has demonstrated that bilateral trade context is an important driver of ISO participation (Prakash and Potoski 2006a). Further, there is no a priori reason to expect that ISO membership among a country's trade partners should influence the country's environmental innovation activity *directly,* as opposed to *indirectly* through its effect on ISO adoption levels in the country. An instrumental variable approach, then, allows us to exploit the exogenous variation in bilateral trade context for causal inference regarding the effect of ISO 14001 participation on environmental innovation.

Second, the spread of voluntary, nongovernmental regulatory regimes might also be driven by the emergence of world society (Meyer et al. 1997). If so, the level of participation in ISO 14001, a global environmental regime, can be predicted by a country's overall linkages with, and exposure to, world society. INGO is a standard indicator for measuring such linkages (Guler, Guillén, and Macpherson 2002). Using the number of INGOs linked to a given country as an instrument, however, can be problematic because the indicator might be correlated with the socioenvironmental consciousness of the citizens in the country and can directly affect environmental innovation efforts. We thus create a spatial lag variable, bilateral trade context in INGO (BTC-INGO), which still captures a country's exposure to a broader world society but would not directly affect the propensity for environmental innovation.

The two instrumental variables, BTC-ISO and BTC-INGO, are constructed as follows:

$$(\text{BilateralTradeContext : ISO})_i = \sum_1^j (\text{ISOMembership}_j * (\text{Export}_{ij}/\text{TotalExport}_i)) \quad (2)$$

$$(\text{BilateralTradeContext : INGO})_i = \sum_1^j (\text{INGOMembership}_j * (\text{Export}_{ij}/\text{TotalExport}_i)) \quad (3)$$

where Export_{ij} represents exports from country *i* to country *j* and ISO (/INGO) Membership_j refers to the ISO(/INGO) membership counts in the export destination country *j.* Total Exports_i represents the total volume of goods exported from country *i* to all of its destinations. Model 7 presents the results from instrumental variable model estimation along with important diagnostic tests statistics.[15] The instrumented ISO participation variable is still positive and significant.

While in model 7, we employ external instruments using a 2SLS estimator, in model 8, we present the results from system GMM estimation in which we employ a set of internal instruments based on the lagged values of the potentially endogenous variable, ISO participation.[16] The GMM estimate of the ISO participation variable is still positive and significant in model 8. The results give more confidence to our claim that ISO participation spurs environmental innovation, taking into account the issues of endogeneity.

About 10 percent of the country-year observations (111 out of 990) included in our analysis do not have a single firm participating in ISO. This suggests the possibility that the causal mechanism leading

ISO to be introduced in the first place needs to be taken into account to evaluate any effect of an increase in ISO participation. Factors—both measured and unmeasured—that promote or deter ISO adoption in a country might also affect the effectiveness of ISO on environmental innovation.

In model 9, we assess such a possibility. We first estimate a probit model with a binary indicator of ISO introduction (equal to 1 for any positive membership in a country) as the dependent variable. This is the selection equation. To avoid the collinearity problem, we include the bilateral trade context in ISO and two political institutional variables (democracy and property rights) only in the selection equation. These variables are significant determinants of the initial ISO introduction in a country but are not significant when included in the outcome equation. Time fixed effects are also included in the selection equation, as we suspect ISO was less widely known in the early years of its introduction, which might explain the zero membership in some countries in the 1990s. Based on the parameter estimates from this selection equation, the inverse Mills ratio for each observation is calculated (Heckman 1979). In the outcome equation, we only use the country-year observations where the ISO is introduced and run a panel linear regression including the inverse Mills ratio as an additional explanatory variable.[17] The inverse Mills ratio is not statistically significant, suggesting there is no strong evidence of selection bias. The outcome equation estimate of ISO participation is still positive: the coefficient estimate is 0.084 with a p-value of .1.[18]

Conclusion

Public managers face regulatory and enforcement challenges in light of declining regulatory budgets and the increasing complexity and scale of environmental challenges. They also face complaints that the regulatory system hampers innovation and makes domestic firms uncompetitive in global markets. Across countries and jurisdictions, voluntary programs have emerged as an important instrument to respond to regulatory challenges, especially as they pertain to "regulation dilemma" issues.

Our article suggests that public managers should evaluate the usefulness of voluntary environmental regulation by considering how it might also foster environmental innovation. We focused on the innovation effects of ISO 14001, a program that public managers are well acquainted with, as reflected in environmental patent counts, and find a positive association between ISO 14001 participation and environmental patent activity at the country level.

> Our article suggests that public managers should evaluate the usefulness of voluntary environmental regulation by considering how it might also foster environmental innovation.

Our article has several important implications for public managers and policy scholars who are interested in utilizing voluntary regulations. The first implication bears on instrument design issues. Public managers should recognize that even within the category of process-focused voluntary regulatory programs, there is significant variation in the types of obligations imposed on their participants and the mechanisms in place to ensure that these obligations are met. The promise of voluntary regulations will be realized only if they impose stringent obligations that compel participants to closely and carefully examine their internal process and systems. There is some evidence that programs requiring participants to adopt more extensive, specific, and demanding environmental management systems show higher levels of environmental improvements (Anton, Deltas, and Khanna 2004; Darnall and Kim 2012). Furthermore, some programs (such as the European Union's Eco-Management and Audit Scheme) require that participants document continual improvements in environmental performance, which creates pressure on firms to find ways to reduce resource waste and to innovate. Future work should examine whether these programs also lead to higher levels of innovation spillover. The design issue is particularly important for public managers because environmental regulators, especially the EPA, have sponsored a large number of voluntary programs (Coglianese and Nash 2009). Public managers who have direct input into program design should assess the consequences of design choices beyond compliance and pollution reduction goals.

Along with assessing the stringency of program obligations, public managers must encourage and support voluntary programs that have mechanisms to ensure that participants do not shirk on program obligations. This is important given the voluntary nature of these programs and the absence of civil and criminal penalties for noncompliance that are typically associated with public regulation. The chemical industry's Responsible Care program illustrates the crucial link between program design and shirking. King and Lenox (2000) attribute the inefficacy of Responsible Care to its institutional design, which did not provide for adequate monitoring and sanctioning. In 2005, Responsible Care modified its institutional design and introduced third-party monitoring to curb shirking. In a recent paper, Vidovic, Khanna, and Delgado (2013) report that once the monitoring mechanisms were introduced, participants' behaviors changed significantly: Responsible Care participants began to pollute less than nonparticipants.[19] Arguably, factors that curb shirking and lead to superior environmental performance might also lead to higher levels of environmental innovation. After all, both are rooted in the desire to reduce resource waste.

Whether and how innovations induced by voluntary regulation lead to productivity gains at the country level is also of interest to public managers (Majumdar and Marcus 2001). Future work should examine the linkage between innovation as a policy output and productivity gains as policy outcomes. Related to this, one can also empirically study the impact of regulation on international competitiveness. Much of the literature debates whether regulatory costs make domestic firms globally uncompetitive. Here the key issues pertain to regulatory costs as a percentage of total cost, price elasticities of products, and so on. However, if there is an upward trajectory in the stringency of environmental regulations worldwide, or at least in the key export markets such as in the European Union, firms adopting stringent voluntary regulatory programs at home might be advantaged. When new regulations are enacted abroad, domestic firms might be well prepared and will not face disruption. In this regard, utilizing properly designed voluntary regulations might assist public mangers in addressing the twin goals of environmental protection and economic growth.

Notes

1. Environmental innovations encompass new or modified processes, practices, systems, and products that benefit the environment and contribute to environmental sustainability (Rennings 2000).
2. The list of programs is available on the EPA's Partners for the Environment home page at http://www.epa.gov/partners/ (accessed January 27, 2014).
3. In some countries, such as the United States, perceptions of regulatory heavy-handedness accentuate the arguably adversarial relationship between governments and firms (Kagan 1991; Kollman and Prakash 2001). The regulatory system creates incentives for firms to litigate at the various stages of the regulatory process in order to dilute or even stall the regulations (Coglianese 1996).
4. For a review, see deLeon and Rivera (2009).
5. See also Ambec et al. (2013) for a comprehensive literature review on the empirical support for the Porter-Linde hypothesis.
6. For data on sectoral and country wise adoption, see http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1686 (accessed January 27, 2014).
7. To capture international (as opposed to within-country) patent activity, we count patent applications submitted directly to the European Patent Office (EPO) as well as international applications filed under the Patent Cooperation Treaty. The data are from the OECD's patent database, which draws on the EPO's World Patent Statistical database (PATSTAT). As a robustness check, we also employ the triadic patent families (TPF) database from the OECD, which includes patents filed together at the EPO, U.S. Patent and Trademark Office, and Japan Patent Office. See Popp (2005) for details on the advantages and disadvantages of the TPF indicator. Following Johnstone et al. (2012), we count the patent applications in each country-year based on the inventor's nationality and priority date.
8. A patent application might indicate inventors from multiple countries. A simple integer counting method would attribute this patent application equally to all countries, leading to the application getting counted multiple times. In this way, an application with inventors from a single country will get counted once, while an application with inventors from multiple countries will get counted multiple times. Recognizing the biases induced in such multiple counting, fractional counting method apportions the invention in relation to the salience of country in the author pool. For example, if there are five authors to the patent application, three belong to country A and one each to countries B and C. Under the simple integer counting method, this application would be counted three times—once each for countries A, B, and C. In contrast, under the fractional counting method, country A would get credit for three-fifths of the patent, while countries B and C would get credit for one-fifth each. Thus, the patent application is counted only once. Indeed, fractional counting has now become the standard methodology in research on innovation.
9. The data are from the OECD's patent database.
10. Export, foreign direct investment, and GDP data are from World Bank.
11. We use the Polity II indicator from Polity IV project. The indicator is a composite index calculated from the coded values of authoritarian (AUTOC) and democratic (DEMOC) components in a country's political system. The index is constructed by subtracting the AUTOC value from the DEMOC value, which provides a single regime score that ranges from +10 (full democracy) to –10 (full autocracy). The codebook can be found at http://www.systemicpeace.org/inscr/p4manualv2010.pdf (accessed January 27, 2014).
12. The property rights protection indicator, from the Heritage Foundation, is "an assessment of the ability of individuals to accumulate private property, secured by clear laws that are fully enforced by the state." The score ranges from 0 to 100; the more certain the legal protection of property, the higher a country's score; similarly, the greater the chances of government expropriation of property, the lower a country's score. More information can be found at: http://www.heritage.org/index/property-rights (accessed January 27, 2014).
13. Year fixed effects are not included, as the *F*-test rejects the hypothesis of significant time effects. A lagged dependent variable is not included, as the Durbin-Watson test upholds the null hypothesis of no serial correlation for the idiosyncratic component of the errors in the fixed-effects panel model, as specified in equation (1). The test does not rely on large-T asymptotics and has good properties in short panels like the one used in this paper. A lagged dependent variable, when added to the model, is not statistically significant, while estimates of other variables hardly change.
14. A small positive value (0.001) was added to the zeroes before taking logarithms. The smallest nonzero value of the environmental patent count in the sample is 0.2.
15. The instruments meet significance and validity criteria. The *F*-statistic (134) for first-stage *F*-test for weak instrument suggests a sufficiently strong correlation between the instruments and the potentially endogenous variable of interest, ISO participation in a country. The Sargan test of overidentifying restrictions *p*-value is .26, so the null hypothesis (that the instruments are exogenous) cannot be rejected.
16. In System GMM (Blundell and Bond 1998), lagged differences of the endogenous variable are used as instruments in the level equation, and lagged levels of the endogenous variable are used as instruments in the first differenced equation. To prevent instrument proliferation (Roodman 2009) we include only a subset ($t-2$ to $t-4$) of the available lags in constructing instruments. Our results hold when we estimate a dynamic panel GMM that includes a lagged dependent variable on the right side of the equation and higher lag orders of the dependent variable as GMM instruments. As was the case in the ordinary least squares models, the estimate of the lagged dependent variable is not statistically significant. The results are available upon request.
17. In the appendix, we present an alternative selection model specification that additionally includes (1) bilateral trade context in INGO membership, (2) size of the manufacturing industry, and (3) seven regional dummies (North America, East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, South Asia, and sub-Saharan Africa) in the probit estimation. The effect of ISO membership still holds with the estimate of 0.089 and a p-value < .5.
18. Although about 30 percent of the country-year observations included in our analysis have zero environmental patents, we consider the zeroes not as structural zeroes, given that other patent counts for those observations are positive: all countries included in the analysis submitted an international patent application at least once during the period covered in this study. Indeed, only 25 out of 990 country-year observations have a zero patent count. As there were five countries (Guatemala, Jamaica, Lebanon, Macedonia, and Pakistan) that never submitted an environmental management–related patent, we ran our main model specification—model 2—excluding these five countries. Our findings with regard to the effect of ISO participation holds: ISO participation variable has an estimate of 0.103 with a p-value of .036, which is close to the original estimate reported in model 2 (0.096). The results are available upon request.
19. See Duflo et al. (2013) on problems with environmental auditing, how auditors can be incentivized to report accurately, and how accurate reporting translates into lower pollution emissions from facilities they have audited.

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Appendix Descriptive Statistics

Environmental Patent	ISO14001	Nonenvironment Patent	GDP Per Capita	Export
Min.: 0.00 Median: 2.00 Mean: 53.93 Max.: 1150.62 Obs.: 990	Min.: 0.00 Median:78.00 Mean: 883.40 Max.: 39556.00 Obs.: 990	Min.: 0.00 Median:51.46 Mean: 2784.21 Max.: 85071.48 Obs.: 990	Min.:1,264 Median: 10.790 Mean: 15450 Max.: 49740 Obs.: 990	Min.: 6.567 Median: 37.137 Mean: 41.346 Max.: 233.545 Obs.: 990
FDI Inflow	Polity	High-Tech Export	R&D Expenditure	Tertiary Education
Min.: –15.048 Median:2.841 Mean: 4.16 Max.: 92.50 Obs.: 990	Min.: –7 Median: 9 Mean: 6.70 Max.: 10 Obs.: 990	Min.: 0.000 Median: 13.438 Mean: 19.406 Max.: 74.178 Obs.: 969	Min.: 0.01611 Median: 1.09321 Mean: 1.65732 Max.: 4.80372 Obs.: 768	Min.: 2.559 Median: 45.660 Mean: 45.300 Max.: 103.900 Obs.: 797

Additional Robustness Checks

	Model 10		Model 11		Model 12	
	GDP-Denominated		TPF Patent Indicator		Controlling Level for Corruption	
	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)	Estimate	Pr(>|*t*|)
ISO participation	0.100	0.015	0.066	0.028	0.097	0.037
Other patents	0.163	0.006	0.037	0.169	0.153	0.009
GDP per capita	10.437	0.017	41.061	0.000	9.795	0.029
GDP per capita^2	–0.592	0.023	–2.081	0.000	–0.619	0.015
Export	0.012	0.523	-0.009	0.556	0.012	0.501
FDI	0.002	0.788	0.000	0.977	0.003	0.759
Democracy	0.002	0.951	0.004	0.885	–0.003	0.940
Property rights	–0.001	0.863	–0.006	0.441	0.001	0.912
Size of economy			–6.764	0.000	1.819	0.473
Freedom from corruption					–0.008	0.332
Observation(country)	990(79)		990(79)		990(79)	
Maximum years	14		14		14	
Country fixed effects	Yes		Yes		Yes	

	Model 13				
	Selection (Probit)			Outcome	
	DV: Any Positive ISO Membership (= 1)			DV: Environmental Patent Count	
	Estimate	Pr(>|z|)		Estimate	Pr(>|t|)
Bilateral trade context: ISO	0.199	0.291	ISO membership	0.089	0.042
Bilateral trade context: INGO	0.295	0.005	Other patents	0.713	0.000
Other patents	–0.006	0.919	GDP per capita	5.235	0.069
GDP per capita	1.052	0.005	GDP per capita2	–0.292	0.070
Manufacturing	0.138	0.000			
Export	–0.009	0.350	Export	0.012	0.012
FDI	0.056	0.160	FDI	0.012	0.493
Democracy	0.062	0.009			
Property rights	0.008	0.358			
Size of economy	0.748	0.000	Size of economy	0.875	0.000
			Inverse Mills ratio	0.907	0.106
Observation (No ISO participating firm)	856(111)		Observation	754	
Maximum years	13			13	
Fixed effects	Time and Region			Region	