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Voluntary Environmental Agreements when Regulatory Capacity is Weak[1]

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Voluntary agreements (VAs) negotiated between environmental regulators and industry are increasingly popular. However, little is known about whether they are likely to be effective in developing and transition countries where local and federal environmental regulatory capacity is typically weak. We develop a dynamic theoretical model to examine the effect of VAs on investment in regulatory infrastructure and pollution abatement in such countries. We find that under certain conditions, VAs can improve welfare by generating more private-sector investment in pollution control and more public-sector investment in regulatory capacity than the *status quo*.
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INTRODUCTION

The conventional approach to industrial pollution control is to establish laws requiring firms to cut emissions. Voluntary regulation, by contrast, provides incentives – but not mandates – for pollution control. In industrialised countries, such regulation has become quite popular over the past two decades (OECD, 1999, 2003). Environmental authorities in developing

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countries, particularly those in Latin America, have also embraced voluntary regulation and are rapidly putting new programmes in place. For example, in Colombia, over 50 voluntary agreements (VAs) between environmental authorities and industrial associations were signed between 1995 and 2003 (Lara, 2003). And in Mexico, ten such agreements involving over 600 firms were signed during the 1990s (Hanks, 2002).

Although voluntary environmental programmes in industrialised countries and those in developing countries share many features, their objectives are generally different. In industrialised countries, regulators typically use voluntary programmes to encourage firms to overcomply with mandatory regulations, or to cut emissions of pollutants for which mandatory regulations do not exist. In developing countries, by contrast, regulators generally use them to help remedy rampant non-compliance with mandatory regulation (Blackman and Sisto, in press). The broad reason for widespread non-compliance with mandatory regulation in developing countries is well known: infrastructure needed to enforce regulations is weak or altogether absent at both the federal and local levels. For example, federal authorities are usually responsible for developing and promulgating written environmental regulation. However, in many cases, such regulation is incomplete, confused, or inappropriate. Local authorities are typically responsible for monitoring and enforcing written regulations. However, in most developing countries, regulatory power is concentrated at the national level and local institutions are relatively weak. In addition, local regulators are often strongly influenced by private-sector interest groups and lack the political will for strict enforcement (World Bank, 1999; Willis *et al.*, 1999; Blackman and Sisto, in press).

The voluntary initiatives that regulators in developing countries are using to try to overcome these constraints include VAs negotiated between environmental regulators and industry associations in specific polluting sectors and/or geographic areas (also known as ‘negotiated environmental agreements’ and ‘voluntary environmental agreements’) as well as public programmes with pre-established rules to which individual firms or facilities are invited to participate.[2] In this paper, we focus on the former type of voluntary regulation. VAs in developing countries often entail four types of commitments. First, a group of industrial firms agrees to make the investments needed to comply with existing mandatory regulations within a certain time period. Second, as quid pro quo, environmental authorities agree not to sanction the firms for non-compliance during this grace period. Third, regulatory authorities agree to make investments needed to eliminate barriers to the enforcement of mandatory regulations, for example, by

[2] See OECD (1999) for a taxonomy of different types of voluntary regulation.

promulgating missing regulations. Finally, environmental authorities promise to subsidise the firm's investment in pollution control. Such VAs are usually widely publicised at the local level.

Blackman and Sisto (in press) present a detailed description and analysis of four consecutive high-profile VAs between regulators and trade associations representing the leather tanning industry in León, Guanajuato, Mexico's leather goods capital, and a notorious environmental hotspot. In each of these VAs, tanners agreed that within 2–4 years, they would cut emissions of organic and inorganic water pollutants by building in-house industrial wastewater treatment facilities, implementing pollution prevention measures, and, in some cases, relocating to industrial parks where common effluent treatment plants could be built. In addition, the tanners promised to improve their handling and disposal of solid and hazardous tanning wastes. As quid pro quo, local environmental authorities agreed not to fine tanners for violating mandatory emissions standards during a 2- to 4-year grace period. Federal and local regulators also agreed to fix longstanding problems with mandatory environmental regulations including a complete lack of rules governing wastewater discharges into local sewers – a responsibility of local regulators – and confused and inconsistent rules governing the handling and disposal of solid and hazardous tanning wastes – a federal responsibility. Finally, under pressure from federal regulators, local environmental authorities agreed to build a municipal wastewater treatment plant, to establish zoning laws for tanneries, and to finance a tannery pollution control education and research centre. All four tannery VAs were signed by top federal environmental authorities and were well publicised. (For a descriptions of other VAs in developing and transition countries, see Lara, 2003; Dvorák *et al.*, 2002; Freitas and Gereluk, 2002; Hanks, 2002; Koehler, 2002.)

Unfortunately, the track record of VAs in developing countries is decidedly mixed. Some appear to have performed as advertised. For example, according to Freitas and Gereluk (2002), a Brazilian nation-wide VA spurred significant reductions in benzene emissions in the metal and petrochemical industries. However, other VAs clearly have not performed well. For example, the aforementioned tannery VAs ultimately were mostly ignored by the signatories (Blackman and Sisto, in press). Similarly, Lara (2003) finds that compliance with a sample of 13 Colombian VAs was negligible.

Such negative evaluations beg the question of whether VAs are likely to be an appropriate regulatory instrument for developing countries. The theoretical economics literature on VAs – which, to our knowledge, focuses exclusively on VAs industrialised country settings – does not provide much reason for optimism (for reviews of this literature, see Lyon and Maxwell, 2002; Khanna, 2001). This literature argues that industry associations participate in and comply with VAs in order to preclude more stringent mandatory regulation (eg, Alberini and Segerson, 2002; Maxwell *et al.*, 2000; Segerson and Miceli, 1998). For example, in Segerson and Miceli (1998), a 'background legislative threat' motivates industry to negotiate a VA. Moreover, the stronger this threat, the more pollution abatement the VA generates. In developing countries with weak regulatory capacity, however, threats of strict mandatory regulation are not credible. Hence, the existing theoretical literature seems to imply that VAs are not likely to be effective in developing countries with limited regulatory capacity.

In this paper, we argue that existing theoretical models of VAs lack the dynamic structure needed to understand the role VAs play in developing countries. We develop a game-theoretic model in which investment in abatement may occur in stages, and we use it to examine the effect of VAs on investment in abatement and in regulatory infrastructure when local and federal regulatory capacity is weak. We find that VAs hold promise for increasing both types of investment and enhancing welfare in precisely those situations where the regulatory capacity is weak. The intuition for this result is as follows. A VA in our model provides a 'grace period' during which no penalties are applied to the industry for failure to comply, but after which more stringent penalties may be applied. A VA thus changes the industry's dynamic investment pattern, reducing short-term investment, but increasing long-term investment. We find that when the probability of effective mandatory regulation is low and the VA allows for a significant increase in penalties for non-compliance, the latter effect outweighs the former, and the VA can enhance welfare.

The analytics used to derive our results are technical and lengthy. In this article, we focus mainly on presenting the results along with the intuition that underpins them. Readers interested in the technical details are referred to Blackman *et al.* (2006a).

The remainder of the article is structured as follows. The next section outlines our analytical model, including the basic assumptions, the timing of the regulators' and polluter's decisions, the notation, and the agents' payoff functions. The third section presents equilibrium results for the *status quo* (absent a VA). The fourth section presents equilibrium results in the case of a VA. The fifth section compares welfare from the *status quo* and VA equilibria. The last section presents a summary and conclusions.

MODEL

We study the interaction of three types of agents: a federal regulator, a local regulator, and a local industry. The two local agents are indexed by $k \in \{L, I\}$ where L denotes the local regulator and I denotes the local industry (Table 1).

Table 1: Notation

j	Index of regulatory instrument: $j \in \{N, V\}$, where N=no VA and V=VA
k	Index of local agents: $k \in \{L, I\}$, where L=local regulator and I=local industry
t	Index of time periods: $t \in \{0, 1, 2\}$
b	Marginal environmental benefit of industry investment in pollution abatement
x_t	Number of additional units of pollution the industry abates in period t, equivalently, the industry's additional investment in durable abatement capital in period t (control variable)
y_t	Local regulator's all-or-nothing investment in regulatory infrastructure in period t, $y_t \in \{0, 1\}$ (control variable)
$B(X_t)$	Environmental benefit from the industry's cumulative pollution abatement capacity
$C(X_t)$	Cost to the industry of its cumulative pollution abatement capacity
D	Uncontrolled industry emissions in period 0
F_j	Fee per unit of emissions levied on the industry by local regulator
I	An element of k, the index of local agents, indicating the industry
L	An element of k, the index of local agents, indicating the regulator
N	An element of j, the index of regulatory instruments indicating no VA
P_j	Lump-sum fine levied on local regulator by federal regulator for failing to install local-level regulatory capacity
$R(y_t)$	Cost to local regulator of investment in local regulatory infrastructure with $R(0)$=0 and $R(1)$=R
V	An element of j, the index of regulatory instruments, indicating a VA
$W(X_t)$	Net social benefit of investment in pollution control=$B(X_t)-C(X_t)$
X_t	Total units of pollution the industry abates in period t, equivalently, cumulative investment in durable abatement capital in period t (state variable)
Y_t	Cumulative investment in local regulatory infrastructure in period t (state variable)
Z_t	Cumulative investment in federal regulatory infrastructure in period t (state variable)
α_t	Period 1 *ex ante* probability of federal capacity being in place in period t, given that it was not in place in $t-1$
δ	Discount factor
π_t^k	Period t expected payoff to agent k
ρ	Period t *ex ante* probability of federal capacity being in place in period t, given that it was not in place in $t-1$
Π_t^k	Two-period discounted payoff to agent k

We consider two types of regulatory instruments: mandatory regulation and a VA. The instruments are indexed by $j \in \{N, V\}$ where N denotes the absence of a VA and V denotes the presence of a VA. Finally, the model has three periods called 'zero', 'one,' and 'two,' indexed by $t \in \{0, 1, 2\}$.

We assume that the industry's pollution is completely uncontrolled in period zero and we use D to denote this level of emissions. In subsequent periods, the industry decides how much to invest in pollution control, or equivalently, how much pollution to abate. We assume that the industry's investments in pollution control constitute a durable good, abatement capital, that can be built up over time. We use X_t to denote the total number of units of pollution that the industry abates in each period, and x_t to denote the number of additional units of pollution abated in each period. Hence, X_t is a state variable (abatement capital) and x_t is a control variable (abatement investment). The industry pays a cost, $C(X_t)$, for abatement capital. We assume that costs are increasing in abatement at an increasing rate, that is, $C(X_t)$ is convex in X_t.

We assume that in order to implement pollution control policies, the local regulator needs both federal-level capacity (eg, laws and regulations) and local-level capacity (eg, local monitoring institutions). In other words, federal- and local-level regulatory capacity are perfect complements. However, both types of regulatory capacity are missing in period zero. Unlike the industry's investment decision which can be incremental, both federal- and local-level investment decisions are 'all-or-nothing.'

The federal regulator's only function in our analysis is to supply the federal-level regulatory capacity. The variable $Z_t \in \{0, 1\}$ indicates the federal regulator's pollution control capacity in period t. We assume that there is a constant hazard rate in each period such that if federal regulatory capacity was not in place in the previous period, it will be in place in the present period with probability ρ. *Ex ante*, the probability of capacity being in place in period t is defined as α_t, where $\alpha_1 = \rho$ and therefore $\alpha_2 = 1-(1-\rho)^2 = \rho(2-\rho)$. Note that $\alpha_2 > \alpha_1$. Hence, from the perspective of an agent in period one, the probability that federal capacity will be in place is increasing over time.

In each period, the local regulator must decide whether or not to build its own regulatory capacity, another dichotomous 'all-or-nothing' choice. The variable $y_t \in \{0, 1\}$ describes the local regulator's investment in local-level regulatory infrastructure. We assume that the local regulator's investment is durable, so that if it is made in period one, no further investment is needed in period two. The variable Y_t denotes the local regulator's cumulative pollution control capacity in period t. Hence, y_t is a control variable and Y_t is a state variable. The cost to the local regulator of investing in regulatory capacity is $R(y_t)$ where $R(0) = 0$ and $R(1) = R$. Each period, the federal regulator threatens to fine the local regulator a lump-sum amount equal to P_j if the local regulator does not build regulatory capacity. This feature of the model is meant to capture pressure to improve environmental quality placed on local regulators by federal regulators. The penalty could be either nonpecuniary (eg, political capital) or pecuniary. In Mexico in the 1990s, for example, federal authorities threatened to withhold disbursements of tax revenues to Guanajuato state if it did not build and begin operating a municipal wastewater treatment plant for the city of León (Blackman and Sisto, in press). Although the federal regulator threatens to sanction the local regulator for failing to invest in regulatory capacity, the federal regulator cannot make good on this threat unless it has built its own regulatory capacity. The local regulator, in turn, threatens to require the industry to pay a fee, F_j, for every unit of pollution it emits. However, as noted above, the local regulator cannot apply this sanction unless both federal regulatory capacity and local regulatory capacity are in place.

In motivating the industry to invest in pollution control, the local regulator can either use mandatory regulation – a fee per unit of emissions – or a VA. A VA has two functions. It designates period one as a 'grace period' during which sanctions are not applied to either the local regulator or to the industry, and it increases the size of these sanctions: both P_j, the fine that the federal regulator levies upon the local regulator, and F_j, the fee that the local regulator requires the industry to pay. A VA increases the size of regulatory sanctions because political constraints on the severity of such sanctions are relaxed when signatories abrogate a formal, high-profile VA. Finally, we assume that the local regulator obtains a benefit, $B(X_t)$, from abatement undertaken by the industry. These benefits arise from, among other things, reductions in damages to human health and environment. The benefits are increasing in abatement at a decreasing rate, that is, $B(X_t)$ is (at least weakly) concave.

We assume that all but two of the parameters of our model are freely observable by all of the agents in the model. These two parameters are the existence in each period of federal regulatory capacity and the existence in each period of local regulatory capacity. A necessary condition for such capacity is that regulators possess the political will to impose sanctions, a capability that is virtually impossible to observe except when successfully demonstrated. Hence, we assume that regulatory capacity is only revealed through enforcement. That is, the local regulator only knows for certain that federal regulatory capacity exists if the federal regulator levies a fine, and the industry only knows for certain that local regulatory capacity exists if the local regulator charges a pollution fee.

The timing of the agents' interactions is as follows. In period zero, only one event occurs: the local regulator offers a VA or not. In period one, the local regulator and the industry decide whether or not to invest. If a VA has not been signed, then fines and fees are levied if the requisite federal and local regulatory capacity is in place, and federal and local regulatory capacity is revealed. If a VA has been signed, then sanctions are not applied in period one (because the VA establishes an enforcement amnesty in this period) and regulatory capacity is not revealed. Finally, in period two, the same events occur regardless of whether a VA has been signed or not: the local regulator and the industry decide whether or not to invest, sanctions are applied if regulatory capacity is in place, and regulatory capacity is revealed.

Given the assumptions and notation presented above, the industry's payoff in each period is comprised solely of two types of costs: the incremental cost of investing in pollution abatement, $(C(X_t)-C(X_{t-1}))$, and the expected total pollution fee levied by the local regulator, $\alpha_t F_j(D-X_t)Y_t$. Hence, the industry's two-period discounted expected payoff with expectation taken at the end of period zero is

$$E\left(\Pi_t^I \middle| t=0\right) = \sum_{t=1}^{2} \delta^{t-1}[-(C(X_t) - C(X_{t-1})) - \alpha_t F_j(D - X_t)Y_t] \quad (1)$$

The local regulator's payoff in each period is comprised of a benefit – the benefit from the industry's pollution abatement, $B(X_t)$ – and three types of costs – the incremental cost of the industry's investment in pollution abatement $(C(X_t)-C(X_{t-1}))$; the cost of installing local regulatory capacity, $R(y_t)$; and the expected penalty for not putting local regulatory capacity in place, $\alpha_t P_j(1-Y_t)$. The inclusion of the cost of the industry's investment in the local regulator's payoff is routine in the industrial organisation literature (see, for example, Tirole, 1988; Baron, 1989). It may be interpreted in either of two ways. First, the local regulator is a traditional welfare maximiser who is unconcerned about distributional issues and who, therefore, treats all benefits and costs equally. Second, the local regulator is strongly influenced by the industry's lobbying as is often the case in developing country settings (Prud'homme, 1995; Blackman *et al.*, 2006b). In any event, the local regulator's two-period discounted expected payoff with expectation taken at the end of period zero is

$$E\left(\Pi_t^L \middle| t=0\right) = \sum_{t=1}^{2} \delta^{t-1}[B(X_t) - (C(X_t) - C(X_{t-1})) - R(y_t) - \alpha_t P_j(1 - Y_t)] \quad (2)$$

***STATUS QUO*: NO VA**

This section focuses on the '*status quo*' situation in which the regulators and the industry do not sign a VA in period zero. We describe and provide intuition for the (somewhat technical) equilibrium conditions for the *status quo*, which are summarised in Table 2.

Table 2: Equilibria

Agent	*Status quo* (no VA)	VA
Local industry	● In each period, invests if and only if the local regulator invests. Invests in period one according to $C'(X_1)=(F_N\rho[1+(1-\rho)\delta]/[1-\rho\delta])Y_1$. ● Expands investment in period two after having invested in period one if and only if the federal and local regulators both invest in period one. Expands according to $C'(X_2)=F_N$.	● Invests if and only if the local regulator invests. Invests in period two according to $C'(X_1)=\alpha_{21}F_V$.
Local regulator	**Case 1:** *the local regulator's cost of installing capacity is less than the avoided expected federal fine for not installing it ($R<\rho P$)* ● Always invests in period one. **Case 2:** *the local regulator's cost of installing capacity is greater than the avoided expected federal fine for not installing it, but less than the certain federal fine ($\rho P<R<P$)* ● In period one, invests if and only if $B(X_1)-C(X_1)-R+\rho[\delta(B(X_2^*(F_N))-C(X_1))]+(1-\rho)[\delta B(X_1)-(\rho[-P_N+\delta(B(X_2^*(F_N))-C(X_2^*(F_N))-R)]+(1-\rho)[-\delta\rho P_N])>0$ ● In period two, invests (if he has not already invested in period one) if and only if the federal regulator invested in period one. **Case 3:** *the local regulator's cost of installing capacity is greater than the certain federal fine for not installing it ($R>P$)* ● In period one, invests if and only if $B(X_1)-C(X_1)-R+\rho[\delta(B(X_2^*(F_N))-(C(X_2^*(F_N))-C(X_1)))]+(1-\rho)[\delta(B(X_1)]+\rho P_N[1+\delta(2-\rho)]>0$ ● In period two, will not invest if he did not invest in period one.	● Invests if and only if $R<\alpha_2P_V$.

Industry

How much will the industry invest in the first period? Because the industry knows that the local regulator cannot successfully charge pollution fees unless local regulatory capacity exists, the industry only invests in pollution abatement in the first period if it determines – by examining the local regulator's payoff function (which is public information) – that the local regulator will install regulatory capacity in the first period.

Even if the industry determines that the local regulator will, in fact, install capacity in the first period, the industry still remains uncertain about whether it could be required to pay a pollution fee in the first period because both the local regulator *and* the federal regulator must install regulatory capacity in order for fees to be successfully levied. Therefore, if the industry decides to invest in pollution abatement, it picks a level of investment, X^*_{N1}, that takes into account uncertainty about the federal regulator's regulatory capacity. It chooses a level of abatement investment according to the first-order condition

$$C'(X_1) = \frac{F_N\rho[1 + (1 - \rho)\delta]}{[1 - \rho\delta]} \tag{3}$$

This chosen level of investment balances the marginal cost of the investment in the first period (the left-hand side of the equation) against the expected marginal benefit of this investment (the right-hand side). The latter is just the expected discounted per unit penalty in both in periods one and two that is avoided by abatement investment. The expected discounted per unit penalty is F_N, the per unit fee, multiplied by $\rho[1+(1-\rho)\delta]/[1-\rho\delta]$, a term that takes into account both uncertainty about the federal regulator's investment in regulatory capacity and discounting of the second period fee. It is easy to show that this term is always less than one because both ρ and δ are, by definition, less than one. It is also easy to show that this term is greater than ρ and increasing in ρ (at an increasing rate). Hence, the optimal level of abatement investment, X^*_{N1}, is smaller than the amount that would equate marginal cost of abatement investment with the marginal penalty, F_N, and the difference is greater the smaller is ρ. In sum, equation (3) implies that the industry's choice of how much to invest in the first period strikes a middle ground between the amount it would invest if it knew for certain that the federal regulator would not install capacity in period one – this amount being zero – and the amount it would invest if it knew for certain that the federal regulator would install regulatory capacity – the amount that equates marginal cost of investment with the per unit penalty, F_N.

It is important to note that the industry's first-period investment, X^*_{N1}, is convex in the probability of federal capacity being installed, that is, when ρ is small, the industry is cautious and invests very little in period one, but as ρ grows large, the industry rapidly increases period one investment. The driver of this convexity is the term $(1-\rho\delta)$ in the denominator of the right-hand side of (3). (The right-hand side of (3) is convex in ρ just as the function $1/(1-x)$

is convex in x.) The term $(1-\rho\delta)$ essentially discounts one of the benefits of first-period investment – the benefit that arises because such investment reduces the incremental cost of investment in the second period. As we shall see, this benefit only arises when federal capacity is installed in the first period. Therefore, it is discounted by ρ – the probability that federal capacity is installed in the first period – as well as by δ.

How much will the industry invest in the second period? We consider two scenarios. The first is that the local regulator lacked incentives to install regulatory capacity in the first period, and as a result, the industry did not invest in pollution control in the first period. In this case, the industry will only invest in the second period if it knows (again, from an examination of the local regulator's payoff function) that the local regulator will invest in the second period. In this scenario, the industry's optimal second-period abatement investment, X^*_{N2}, will depend on the action the federal regulator took in the first period. If the federal regulator invested in the first period, then the industry will invest according to the following first order condition

$$C'(X_2) = F_N \tag{4}$$

If the federal regulator did not invest in the first period, then the industry will invest according to

$$C'(X_2) = \rho F_N \tag{5}$$

These conditions simply dictate that in selecting a second-period level of investment, X^*_{N2}, the industry balances the marginal cost of the abatement in the second period (the left-hand side of each equation), against the expected marginal benefit of abatement (the right-hand side).

The second scenario for the industry's second-period investment is that the local regulator installed regulatory capacity in the first period, and as a result, the industry invested in pollution control according to equation (3). In this scenario, too, the industry's decision to undertake additional investment depends on the federal regulator's actions in the first period. If the federal regulator installed regulatory capacity in the first period, then the industry will undertake investment in the second period above and beyond that it already undertook in the first period if and only if the following condition is met

$$\rho(1 + \delta(2 - \rho)) < 1 \tag{6}$$

It is easy to show that this condition is only met when ρ, the *ex ante* probability that federal authorities invest in regulatory capacity in each period given that it has not yet done so, and δ, the discount factor, are sufficiently small. Intuitively, the reason is that when the probability that federal authorities invest in regulatory capacity in the first period is small, and when the discount factor is small, the industry's first-period abatement investment is also relatively small, and would be too small to suffice as a second-period level of abatement investment in situations where federal authorities invest in the first period. When the industry expands it abatement investment in the second period, it does so until the marginal cost of further investment is equal to the marginal per unit emissions fee, that is, until equation (4) is satisfied. We simplify the analysis in the remainder of the paper by restricting it to values of ρ and δ such that the 'expansion condition' given by equation (6) holds.

If the federal regulator did not install capacity in the first period, then the industry will not invest in the second period, regardless of what the federal regulator does or does not do in the second period. The reason is that the industry's first-period investment is at least as great as that it would want to have in place in the second period given continuing uncertainty about whether federal regulatory capacity will be in place in the second period.

Local regulator

How does the local regulator decide whether or not to install capacity – a dichotomous 'all-or-nothing' choice – when no VA exists? In general, the local regulator makes this decision by comparing the costs and benefits of this investment. The cost is always simply R. The benefits have two components: (a) the avoided expected federal fine for not installing local capacity, and (b) the net expected benefit of the pollution abatement that the industry undertakes when it determines that the local regulator will install regulatory capacity. The direct benefits and costs that the local regulator considers in making its decision depend on three parameters: the cost of installing local regulatory capacity, R; the *ex ante* probability that the federal authority installs federal regulatory capacity given that it has not done so previously, ρ; and the federal fine for not installing local capacity, P_N. These parameters define three cases. For each, we describe the conditions under which the local regulator invests, and we provide intuition for these results.

Case 1 occurs when the local regulator's cost of installing regulatory capacity is less than the avoided expected federal fine for not installing it, that is, when $R < \rho P_N$. In this case, the local regulator will always install capacity in the first period. The reason is that the cost to the local regulator of installing regulatory capacity is less than one of the two components of the benefit from this investment – component (a), the avoided expected federal fine for not installing regulatory capacity. Clearly, then, the cost of installing capacity must be less than both components of the benefits added together.

Case 2 occurs when the local regulator's cost of installing regulatory capacity is greater than the avoided expected federal fine for not installing it, but is less than the certain federal fine, that is, when $\rho P_N < R < P_N$. In this case, a necessary and sufficient condition for the local regulator to invest in the first period is that the benefits exceed the costs. Table 2 presents a mathematical condition derived from a comparison of the benefits and costs for this case. Whether or not the condition holds depends on the specific parameterisation of the model. If it does not hold, then the local regulator does not install capacity in the first period, and must decide whether to install capacity in the second period. The local regulator makes this decision by comparing the benefits and costs of installing capacity in the second period. It turns out that a necessary and sufficient condition for the benefits to exceed the costs is that the federal regulator has installed capacity in period one.[3]

Case 3 occurs when the local regulator's cost of installing regulatory capacity is greater than the certain federal fine for not installing it, that is, $R > P_N$. Here again, the local regulator decides whether or not to install capacity in the first period by comparing the expected benefits and costs of doing so. Table 2 presents a necessary and sufficient condition for investment derived from the regulator's comparison of benefits and costs for this case. If this condition is not met so that the local regulator does not install capacity in the first period, then the local regulator must decide whether to install capacity in period two. Again, it does this by comparing the benefits and costs of this investment. However, it turns out that the fact that the cost of the first-period investment exceeds the benefits necessarily implies that the costs of second-period investment exceed the benefits, even if the federal regulator has already installed capacity in period one. Therefore, if the local regulator does not invest in the first period, it will not invest in the second period either.

[3] To see this, note that if the federal regulator has installed federal regulatory capacity in period one, then the local regulator faces a certain penalty, P_N, if it does not install local regulatory capacity in period two. We know that for Case 2, the cost of installing local regulatory capacity, R, is less than one of the two components of the benefits of installing capacity – component (a), the avoided certain penalty, P_N – and is therefore clearly less than both components added together. Hence, if the federal regulator has installed capacity in period one, the local regulator will install capacity in period two. If, on the other hand, the federal regulator did not install capacity in period one, it is easy to show the cost of installing capacity will outweigh the benefits. Hence, if the federal regulator has not installed capacity in period one, the local regulator will not install capacity in period two.

VOLUNTARY AGREEMENT

Under a VA, neither the industry nor the local regulator have any reason to invest in period one because the grace period ensures there is no possibility that they will be penalized in this period. The industry's and the local regulator's only decision is how much to invest in the second period. The equilibrium conditions are quite simple (see Table 2).

Industry

The industry only invests in pollution abatement in the second period if it determines (from an examination of the local regulator's payoff function) that the local regulator will invest. If the industry does invest, then it selects a level of investment, X^*_{V2}, dictated by the first-order condition

$$C'(X_2) = \alpha_2 F_V \tag{7}$$

Here again, the optimal level of investment balances the marginal cost of investment (the left-hand side) and the marginal expected benefit (the right-hand side), which in this case is simply the expected per unit pollution fee under the VA.

It is useful to compare the industry's investment in pollution abatement under the VA and the *status quo*. The industry's investment under the VA, X^*_{V2} (given by equation (7)), exceeds the total second-period investment it would choose under the *status quo* in the case where the federal regulator did not install capacity in the first period, X^*_{N2} (given by equation (5)). The reason is that the probability a pollution fee will be charged under the VA, α_2 which is equal to $\rho(2-\rho)$, exceeds the probability that a fee will be imposed under the *status quo*, ρ, and the per unit fee under the VA, F_V exceeds the fee under the *status quo*, F_N. Since by definition, industry's abatement investment in the second period, X^*_{N2} is at least as great as its abatement investment in the first period, X^*_{N1}, this logic also implies that the industry's investment under the VA, X^*_{V2}, is at least as great as the first-period investment it would choose under the *status quo*, X^*_{N1}. Hence, the only scenario in which the industry's investment under the VA could possibly be lower than its investment under the *status quo* is when the federal regulator installs capacity in the first period. In this case, the industry faces a certain pollution fee in the second period under the *status quo*, and the industry's second-period investment, X^*_{N2}, is given by equation (4). By definition, however, this scenario (federal investment in regulatory capacity in the first period) is highly unlikely when ρ is small. In sum, in expectation, the industry's investment under the VA will be larger than under the *status quo* as long as ρ is small.

Local regulator

Under a VA, the local regulator compares the cost of installing regulatory capacity, R and the benefit, which is simply the avoided expected penalty, $\alpha_2 P_V$. The local regulator installs capacity if and only if the latter exceeds the former. In using this simple decision rule, the local regulator might appear to be ignoring the net benefits and costs of the industry investment. Actually, however, the local regulator is simply making its best response to the investment strategy it expects the industry to pursue: the local regulator takes as given the industry's investment decision and makes its own best decision.

WELFARE ANALYSIS

To this point, we have analysed the behaviour of the industry and the local regulator with a VA and under the *status quo*. We have shown that a VA can induce greater investment than the *status quo* in period two, but also that a VA fails to produce any investment in the period one. Hence, to assess the overall desirability of a VA relative to the *status quo*, we must conduct a detailed analysis of social welfare.

Welfare function

We construct welfare, W_j, as the discounted expected benefit from the industry's total investment in pollution abatement, net of: the cost of that investment; the cost of any investment in local regulatory capacity; and any penalty paid by the local regulator to the federal regulator. In this construction, welfare is the net benefit of regulation to local (*versus* national) stakeholders. We omit the costs paid by the federal regulator to install regulatory capacity because the federal regulator's investments are exogenous to the local regulator's and the industry's decisions and, therefore would simply net out in a comparison of welfare generated by the VA *versus status quo* regulation. Also, we omit fees paid by the industry to the local regulator since they represent a transfer among local agents. Given these assumptions, the general form of the welfare function is identical to the local regulator's payoff function given by equation (2).[4]

We assume simple functional forms for the benefit and cost functions to facilitate the numerical simulation presented in the next section. Specifically, we assume a linear benefits function, $B(X) = bX$, where b is a parameter and where $F < b$ so that per unit pollution fees are never so large as to induce

[4] It is standard to include both benefits (to society) and costs (to industry) in a social welfare function. See, for example, Segerson and Miceli (1998) or Maxwell *et al*. (2000).

overinvestment. In addition, we assume a quadratic cost function, $C(X) = X^2$.[5] Finally, as noted above, fees and fines under the VA are larger than under the *status quo*. We assume that this differential is sufficiently large so that even when discounted for uncertainty about the federal regulator's actions, expected fees under the VA are greater than certain fees under the *status quo* – that is, $\alpha_2 F_V > F_N$ – and expected fines under the VA are greater than certain fines under the *status quo* – that is, $\alpha_2 P_V > P_N$. These assumptions about the relative size of fees and fines under the VA and the *status quo* embody our argument that the VA enables regulators to impose greater expected penalties – without these assumptions, the VA could result in smaller expected penalties compared to the *status quo*. These assumptions have the effect of ensuring that the VA has the potential to enhance welfare compared to the *status quo*.

As discussed in Section 3, the local regulator's investment behaviour, and as a result the industry's investment behaviour, depends on the parameters that determine the local regulator's direct cost and benefits of investment. The cost is always simply R, while the benefits depend upon the fines incurred by the local regulator for not installing such capacity, P_N and P_V, and upon the two parameters associated with the probability that the federal regulator installs capacity, ρ and α_2. Therefore, to derive equilibrium results, we must consider four 'welfare cases' that are defined by these parameters (for details, see the Appendix A). Note that we have four cases rather than just the three discussed in Section 3.2, because the welfare analysis involves two additional parameters: α_2 and P_V. The general form of the welfare function for each of these four cases is given by equation (2). Because this general form is quite unwieldy, we simplify it by taking into account the behaviour of the local regulator and the industry in each case. (For example, in cases where the local regulator does not invest in the first period, we omit the benefits and costs of investment for both the local regulator and the industry since the industry does not invest in the first period when the local regulator does not.) As a result, the simplified welfare function for each of these four cases is different, although each is entirely consistent with equation (2) (for details, see Appendix A).

Numerical simulations

In this section, we compare the expected value of welfare under the VA, $E(W_V)$, to the expected value of welfare under the *status quo*, $E(W_N)$. It is

[5] The assumption of linear benefits and quadratic costs is purely a simple way to ensure a concave social welfare function and does not affect the results in any qualitative way. For a similar approach, see Glachant (2003) which also assumes linear benefits and quadratic costs.

Table 3: Numerical simulations[a]

	Status quo			VA			
ρ prob. fed capacity given no capacity last period	X^*_{N1} t=1 industry investment without VA	$X^*_{N2}\|(Z_1{=}1)$ t=2 industry investment without VA given t=1 fed capacity	$E(W_N)$ expected welfare without VA	X^*_{V2} t=2 industry investment with VA	$E(W_V)$ expected welfare with VA	$E(W_V)/E(W_N)$ (expected welfare w/VA)/(expected welfare without VA)	Expansion condition[b]
Case W1 ($R<\rho P_N$)							
0.00	0.000	0.500	0.000	0.000	0.000		0.000
0.05	0.049	0.500	1.112	0.146	1.297	1.166	0.138
0.10	0.099	0.500	2.219	0.285	2.492	1.123	0.271
0.15	0.153	0.500	3.322	0.416	3.590	1.081	0.400
0.20	0.210	0.500	4.427	0.540	4.598	1.039	0.524
0.25	0.270	0.500	5.537	0.656	5.519	0.997	0.644
0.30	0.335	0.500	6.660	0.765	6.358	0.955	0.759
0.35	0.405	0.500	7.802	0.866	7.121	0.913	0.870
0.40	0.481	0.500	8.973	0.960	7.811	0.870	0.976
Case W2 ($\rho P_N<R<P_N$)							
0.00	0.000	0.500	0.000	0.000	−0.450	—	0.000
0.05	0.049	0.500	0.611	0.146	0.847	1.386	0.138
0.10	0.099	0.500	1.716	0.285	2.042	1.190	0.271
0.15	0.153	0.500	2.819	0.416	3.140	1.114	0.400
0.20	0.210	0.500	3.923	0.540	4.148	1.057	0.524
0.25	0.270	0.500	5.033	0.656	5.069	1.007	0.644
0.30	0.335	0.500	6.156	0.765	5.908	0.960	0.759
0.35	0.405	0.500	7.299	0.866	6.671	0.914	0.870
0.40	0.481	0.500	8.472	0.960	7.361	0.869	0.976
Case W3 ($\rho P_N<P_N<R<\alpha_2 P_V$)							
0.00	0.000	0.500	0.000	0.000	−1.080	—	0.000
0.05	0.049	0.500	−0.088	0.146	0.217	2.471[c]	0.138
0.10	0.099	0.500	1.018	0.285	1.412	1.387	0.271
0.15	0.153	0.500	2.119	0.416	2.510	1.185	0.400
0.20	0.210	0.500	3.219	0.540	3.518	1.093	0.524
0.25	0.270	0.500	4.321	0.656	4.439	1.027	0.644
0.30	0.335	0.500	5.430	0.765	5.278	0.972	0.759
0.35	0.405	0.500	6.550	0.866	6.041	0.922	0.870
0.40	0.481	0.500	7.690	0.960	6.731	0.875	0.976

For all three cases: b=10; D=2; P_N=1; P_V=6; F_N=1; F_V=3; δ=0.9. For Case *W1*, R=0; for Case *W2*, R=0.5, and for Case *W3*, R=1.2. We vary R to meet the conditions that define each case.

[a] We omit case *W4* described in the Appendix A. In this case, neither the local regulator nor the industry ever invest under the *status quo* or under the VA. Higher fines and fees under the VA reduce local welfare below that for the *status quo*.

[b] See equation (6). This condition restricts the values of ρ to those in the first column.

[c] For this case, welfare is negative without the VA. We omit the negative sign on the ratio, so as to avoid the false impression that the VA performs worse than the no-VA case.

difficult to establish analytical comparative statics on the magnitude of $E(W_V)$ relative to $E(W_N)$. Therefore, we rely on numerical simulation. Our results are presented in Table 3.[6,7]

We emphasise one striking and broad finding: in each of the first three welfare cases, the VA's performance relative to the *status quo* is better the lower the probability that the federal regulator will install regulatory capacity in each period (given that the regulator has not installed capacity previously). That is, the ratio of $E(W_V)$ to $E(W_N)$ is decreasing in ρ. In fact, in our simulations, $E(W_V)$ only exceeds $E(W_N)$ when ρ is low. In case $W1$, the VA is only socially beneficial for $\rho \leqslant 0.20$, and in cases $W2$ and $W3$, the VA is only socially beneficial for $\rho \leqslant 0.25$.

The intuition for these results is as follows. For $E(W_V)$ to exceed $E(W_N)$, the welfare gained from investment in the second period under the VA, X_{N2}, must be large enough to outweigh the fact that the VA elicits no investment in the first period. This can easily occur when ρ is small because in such situations, the industry typically invests very little in either the first or second period under the *status quo*. Recall that the industry's investment strategy under the *status quo* is to make one investment decision in the beginning of the first period, to wait and see whether the federal regulator installs capacity later in this period, and then make a second investment decision in the beginning of the second period. The industry's first-period abatement investment is very small for small values of ρ due to the convexity of the investment function, which we discussed in Section 3.1. The industry's second-period investment strategy is to invest if and only if the federal regulator installed capacity in the first period, which is unlikely when ρ is small. Hence, when ρ is small, expected industry investment in both the first and second periods is quite low under the *status quo*, and as a result, the local regulator's decision to use a VA costs little in terms of foregone first-period investment. At the same time, the VA allows for an increase in the pollution fee, which amounts to a penalty for failing to invest in abatement. This increased penalty induces the industry to make a greater second-period investment than it would under the *status quo*. When ρ is small, the increased second-period investment outweighs the lost first-period investment, and the VA improves social welfare.

[6] We omit case *W4* wherein the local regulator never installs regulatory capacity under any conditions and, therefore, industry never invests under any conditions.

[7] In the simulations we have examined, industry profits are typically lower under a VA in exactly the circumstances in which the VA enhances welfare. This is not a fundamental problem, however, because the regulator can allocate some of the increase in welfare to providing technical assistance or other subsidies to obtain the industry's cooperation.

Note the difference between our findings and those of Segerson and Miceli (1998). While we find that a VA is only socially desirable when the probability of enforcing mandatory regulations is low, Segerson and Miceli find that a VA is always socially desirable, regardless of the probability of enforcing mandatory regulation. The reason for the difference is twofold. First, in Segerson and Miceli's model, a VA primarily serves to reduce transaction costs, so it is always socially desirable, all other things equal. We do not impose such *ad hoc* assumptions, which would bias our results in favour of a VA. Second, the model of Segerson and Miceli is essentially static – it only allows for the industry to invest at a single point in time. In our model, by contrast, the VA plays an inherently dynamic role. It creates an enforcement amnesty in the first period but increases the penalties regulators can wield in the second period and, in doing so, it eliminates the industry's first-period abatement investment and increases its second-period abatement investment. As long as the period-by-period probability of enforcing mandatory regulation is small, this tradeoff turns out to be socially beneficial.

CONCLUSION

VAs are common in developing as well as developed countries, but they play different roles and operate differently in these different settings. In this paper, we have presented a dynamic model of a VA in a developing country where environmental regulation is not being enforced due to a lack of requisite institutional infrastructure at the federal and local levels. We focused on the interaction between a local regulator and a local industry, both operating under uncertainty about when federal environmental regulatory capacity is likely to develop. The VA in our model provides a 'grace period' during which no penalties are applied to the industry for failure to invest in pollution abatement in the short term, but more stringent penalties can be applied in the longer term. A VA changes the industry's dynamic abatement investment pattern, eliminating first-period investment but increasing second-period investment. We find that when the probability of federal enforcement is low, and the VA allows for a significant increase in penalties, the latter effect outweighs the former, and the VA can enhance welfare. Our analysis provides a new rationale for the use of VAs, one we believe may be of considerable importance in developing and transition countries where regulatory capacity is weak.

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APPENDIX A

See Welfare function by case given in Table A1.

Table A1: Welfare function by case

Case W1: $R<\rho P_N<P_N<\alpha_2 P_V$
VA: $\delta[bX_{V2}-(X_{V2})^2-R]$
No VA: $bX_{N1}-X_{N1}{}^2-R+\rho[\delta[bX_{N2}-(X_{N2}{}^2-X_{N1}{}^2))]+(1-\rho)\delta bX_{N1}$
Case W2: $\rho P_N<R<P_N<\alpha_2 P_V$
VA: $\delta[bX_{V2}-(X_{V2})^2-R]$
No VA: $\rho(-P_N+\delta(bX_{N2}-X_{N2}{}^2-R))+(1-\rho)(-\delta\rho P_N)$
Case W3: $\rho P_N<P_N<R<\alpha_2 P_V$
VA: $\delta[bX_{V2}-(X_{V2})^2-R]$
No VA: $bX_1-(X_1{}^2)-R+\rho(\delta bX_2-(X_2{}^2-(X_1{}^2)))+(1-\rho)\delta bX_1$ [if Y_1=1]$-\rho P_N[1+\delta(2-\rho)]$ [if Y_1=0]
Case W4: $\rho P_N<P_N<\alpha_2 P_V<R$
VA: $-\delta\alpha_2 P_V$
No VA: $-\rho P_N[1+\delta(2-\rho)]$