Policy persistence in environmental regulation

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Abstract

We study the optimal emission standards under uncertain pollution damages and transaction costs associated with policy changes in a dynamic setting. We consider three alternative forms of transactions costs and show that they can lead to different kinds of delays of policy changes or smaller scales of these changes. Thus, policy persistence can be a rational response of forward-looking policy makers to future transaction costs, rather than an inefficient outcome of the current political process. © 2003 Elsevier Science B.V. All rights reserved.

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Economists have long taught that the efficient level of effluent (or more generally any externality) occurs when the marginal benefits and costs of pollution are equated. Despite this clear policy advice, there is considerable agreement that economists’ influence on environmental policy making has been modest (Hahn, 2000). Rather, there is a strong sense that many times it is the political process, in particular the interaction of interest groups, that shapes the final design of environmental policy and any changes in that policy over time (Maloney and McCormick, 1982; Keohane et al., 1999; Yandle, 1989).

An important reason for this belief is the predominant presence of policy persistence; the fact that policies such as pollution standards tend to change slowly if at all and tend to change in small steps. In this paper, we analyze this phenomenon of policy persistence in the context of transaction costs associated with policy changes, and show that the persistence can be a rational response of policy makers to these costs in a dynamic and uncertain framework. Transaction costs may be due to different forces, including interest group lobbying, monitoring and reporting, etc. and may cause different kind of difficulties in changing policies. Correspondingly, we study three kinds of transaction costs.

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First, transaction costs of policy changes may arise when new policies create policy trends that are difficult to reverse. Significant agreement is emerging in the literature concerning the difficulty of reversing a policy once it has been established. For example, Coate and Morris (1999) shows that the introduction of a policy invites agents to undertake actions that allow them to benefit from the policy. These benefits, in turn, create incentives for these agents to protect their interests in the form of political pressure and lobbying. Likewise, Dixit (1996) argues that “policy acts shape the future environment by creating constituencies that gain from the policy, who will then fiercely resist any changes that take away these gains.” This research points to the existence of policy trends which are engendered by a policy change: the beneficiaries of such a change are likely to fight to prevent the changes from being reversed, and even to assist further changes along the trend. In environmental regulation, tighter standards may induce firms to invest in abatement technology. The investment is likely sunk, and thus once it is undertaken, these firms may oppose any loosening of the standards in order to keep their competitive advantage. For example, suppose certain auto makers invest heavily in alternative fuel automobiles (such as the hybrid cars) in response to a tightening of government’s air pollution regulation (say more strict standards under the Clean Air Act). Then to keep their competitive advantage, these firms would have incentive to lobby against any relaxation of the regulation, and possibly even lobby for further regulation.

Second, transaction costs may come in the form of a pre-existing policy trend (which is not caused by any policy changes) that the regulatory authority faces. For example, environmental Kuznets curves imply that as the income level rises, a regulatory authority may face pressure to relax its environmental regulation at early stages of development, and to tighten regulation at more advanced stages. In the heyday of the environmental movement in 1970’s, it was politically impossible for any regulatory authority to loosen an environmental standard. Public opinion, technological development, and other factors may impose such policy trends on regulators, overcoming any lobbyist’s action.

Third, some transaction costs arise regardless of the direction of policy changes. These include monitoring and measurement, and equally heavy political lobbying of controversial policies by both sides (environmentalists and industry, for example). It is not uncommon for the government to be criticized on both fronts when it announces a new regulation. For example, when the US government announced its new policy to protect the west coast salmon and steelhead, property owners criticized that the policy went too far, while environmentalists considered the policy inadequate and announced plans to sue the government (New York Times, 2000).

In the first case, transaction costs in the current period may be symmetric for policy changes in both directions (tightening or loosening the standard), but depending on the resulting policy trend, future transaction costs will be asymmetric. The costs are asymmetric in all periods in the second case, and are symmetric in all periods in the third case.

In a static framework, the effects of transaction costs on policy changes have been analyzed by Stavins (1995) in the context of emission permits. His results indicate that transaction costs cause the efficient solutions to be closer to existing ones, leading to policy persistence. The static analysis provides a very useful, but partial, framework of understanding policy persistence. It cannot deal with case one, where new policies create (ir-
reversible) trends in the future. More generally, if transaction costs lead policies to be persistent, then the new policies will themselves be subject to these costs in the future when changes become necessary. In setting a new standard, policy makers are likely to respond not only to the current costs, but also to future costs. This consideration becomes even more important if there is uncertainty about the costs and benefits of pollution control, since future information may render the new policy suboptimal and call for further changes.

The question we address in this paper, therefore, is how the three types of transaction costs contribute to (or reduce) policy persistence when the environmental authority is uncertain of the damages of the effluent and is cognizant of these costs (especially in the future). We emphasize dynamic considerations and uncertainty, and study how higher uncertainty increases or reduces policy persistence in a dynamic framework with the three types of transaction costs. For this purpose, we do not study the process by which these costs arise. Rather, like Stavins (1995), we take the costs as given, and investigate the optimal response of the policy makers in choosing the level of the environmental policy.

This paper is not the first attempt to investigate the effects of transaction costs on policy making in a dynamic framework. Pindyck (2000) studied the timing of an environmental policy when the new policy is irreversible. Given an exogenously decided new standard, he showed that the authority has incentive to delay adopting the standard if the authority is uncertain about the standard’s efficiency but can learn more about it in the future. This conclusion is similar to findings of real option theory where private decision makers delay investment facing uncertainty and irreversibility (Arrow and Fisher, 1974; Dixit and Pindyck, 1994; and Kolstad, 1996). The situation he analyzed is similar to case two of the transaction costs: the new policy is proposed along the existing policy trend and is thus irreversible.

Delays in enacting new policies are one form of policy persistence: policies are not changed even when they would have been in the absence of transaction costs. In this paper, we also deal with another form of persistence: the reduced scale of the new policy when the regulator can freely choose the timing of a policy change. We show that in case two, the regulator will reduce the size of the policy change facing uncertainty and irreversibility. Since she can always change the new standard in the future along the trend but not against the trend, she would reduce the size of any such change and thus the likelihood that the new policy moves too much along the trend and cannot be reversed. Delay then is a special case where the scale of the change is zero. Further, we extend Pindyck (2000) to the other two cases of transaction costs. Case one is particularly interesting as the direction of irreversibility is endogenous. Since any policy change will create an irreversible trend, the policy maker acts as if there is a fixed transaction cost: the existing policy is not changed (or the change is delayed) until sufficiently strong evidence emerges, when the policy is changed at a large scale.

The paper is organized as follows. In Section 1, we lay out the basic problem faced by the regulatory authority, and the different forms of transaction costs. We study symmetric transaction costs (case three) in Section 2 and asymmetric transaction costs in Section 3. We conclude the paper in Section 4 with a discussion of the implications of these results generally for policy.
1. Model setup and alternative forms of transaction costs

We consider a flow pollutant that causes environmental damage only in the period it is emitted. Let \( e_t \) be the emission standard, and consequently the actual emission level in period \( t \), with damage given by \( D(e_t) = \theta_t d(e_t) \), \( d' \geq 0, d'' > 0, d(0) = 0 \) and \( d'(0) = 0 \). The damage coefficient \( \theta_t \) is a random variable that is observed at the beginning of period \( t \). The benefit of emitting \( e_t \) (i.e. the saved abatement cost) is given by \( B(e_t) \), with \( B'' < 0, B(0) = 0 \) and \( B'(0) > 0 \). The information facing the regulatory agency overtime is described by the stochastic process \( \{\theta_t, t \geq 0\} \).

The regulatory agency chooses a standard for per period emissions to maximize social welfare. If the policy is not rigid so that the agency can change the standard costlessly, it can simply set the current period standard as \( \text{arg max}_e B(e) - \theta_t d(e) \). If future information renders this standard inappropriate, the authority can then set a new standard based on the new information.\(^2\) That is, the agency’s problem is essentially static. However, if the current standard is costly to change in the future, the agency’s problem is dynamic: the current standard should be set to maximize the expected present value of net payoffs, subject to the amount of information available and transaction costs associated with future adjustments to the standard. We assume that the agency is risk neutral with discount rate \( r \).

Under symmetric transaction costs (case three), the cost for both more and less strict policy changes is given by \( c(\cdot) \) that is symmetric about the origin. In particular, \( c(0) = 0 \), and for \( x > 0 \), \( c'(x) > 0 \) and \( c''(x) \geq 0 \).\(^3\) For example, if the current standard is \( e_0 \) and the new standard is \( e_1 \), then the transaction cost is \( c(e_1 - e_0) \).

For case two where a policy trend already exists, we follow Pindyck (2000) to assume that the policy can only be changed along the trend, and the change is irreversible. In particular, if the policy trend is toward tighter pollution control, the policy maker faces the following constraint: \( e(t_1) \geq e(t_2) \) for \( t_2 > t_1 \). Similarly, if the trend is toward loosening control, the constraint is \( e(t_1) \leq e(t_2) \) for \( t_2 > t_1 \). This assumption of absolute irreversibility of the trend greatly simplifies the analysis, but as we discuss later, is not essential to our major results.

In case one, there is no cost in changing the policy in the current period, before the trend is set. However, once the trend is set, case two transaction costs arise for all future periods. We assume away current period costs to highlight the impacts of future costs engendered by a policy change. Again, the assumption simplifies the analysis, but is not essential to our results.

We assume that the damage coefficient \( \theta_t \) follows a geometric Brownian motion process:

\[
\frac{d\theta_t}{\theta_t} = \alpha dt + \sigma dz_t,
\]

where \( dz_t \) is the increment of the Wiener process. That is, \( dz_t = x(t) \sqrt{dt} \), where \( x(t) \sim N(0, 1) \) with \( \text{cov}(x(t_1), x(t_2)) = 0 \) for \( t_1 \neq t_2 \). The parameter \( \alpha \) measures the “trend” of the growth rate of \( \theta_t \), and \( \sigma \) measures the level of uncertainty. We assume \( \alpha < r \); otherwise, the pollution damage would increase too quickly to allow any emission. According to this

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\(^1\) Throughout the paper, we assume that the policy standard is binding: firms will emit up to the allowed level.

\(^2\) We assume away any possible transaction costs the firms may incur responding to policy changes.

\(^3\) For simplicity, we assume away fixed transaction costs that are independent of the scale of the policy change.
formulation, some uncertainty about the future values of $\theta$ always remains. New information arrives in the form of an observed $\theta$ value that affects the expected future levels of $\theta$. For many environmental problems, uncertainty about pollution damages may never be fully resolved; human preferences and populations are ever changing; thus, even as some sources of uncertainty are resolved, new ones arise. The process in (1) successfully captures this idea and has been widely used (for example, Dixit and Pindyck, 1994). 4

2. Symmetric transaction costs

In the case of symmetric transaction costs, future changes in both directions are costly; thus, the current optimal standard depends on the specific forms of the benefit and damage functions of $e$, as well as the transaction cost function $c(\cdot)$. Higher uncertainty may cause the standard to increase or decrease, and its impact on policy persistence is ambiguous.

Suppose the initial standard is $e_0$. In period $t$, the agency observes the value of $\theta_t$ and chooses the new standard for this period. Let $I_t$ measure the magnitude of the policy change. Then the agency’s optimal decision problem is

$$J(\theta_0, e_0) \equiv \max_{I_t} E \int_0^\infty \left[ B(e_\tau) - \theta_\tau d(e_\tau) - c(I_\tau) \right] e^{-r\tau} d\tau \quad \text{s.t.}$$

$$d\theta_\tau = \alpha \theta_\tau d\tau + \sigma \theta_\tau dz_\tau \quad \dot{e}_\tau = I_\tau, \quad e_0 \text{ given.}$$

From Bellman’s Principle of Optimality and Ito’s Lemma, we know the optimal policy adjustment $I_t$ satisfies:

$$rJ(\theta_t, e_t) = \max_{I_t} \left\{ B(e_t) - \theta_t d(e_t) - c(I_t) + \alpha \theta_t J_{\theta} + \frac{1}{2} \sigma^2 \theta^2 J_{\theta^2} + J_e I_t \right\}.$$  \quad (2)

Thus the first order condition on $I_t$ is

$$c' (I_t) = J_e(\theta_t, e_t);$$  \quad (4)

the marginal adjustment cost of the policy change should equal the expected present value of all future marginal benefits, measured by $J_e(\theta_t, e_t)$.

Uncertainty affects the optimal policy $I_t$ through changing $J_e$. Note that how $J_e$ responds to a higher $\sigma^2$ does not necessarily depend on the sign of $I_t$. To see this, let $Y(\theta, e) = J_e(\theta, e)$. Taking derivatives of both sides of (3) with respect to $e_t$ and using (4), we get

$$Y(\theta_t, e_t) = B'(e_t) - \theta_t d'(e_t) + \alpha \theta_t Y_{\theta} + \frac{1}{2} \sigma^2 \theta^2 Y_{\theta^2} + Y_e I_t.$$  \quad (5)

As $\sigma^2$ increases, $Y$ is likely to rise if $Y_{\theta^2} > 0$, or if $Y(\theta, e)$ is convex in $\theta$. This observation is intuitive: if $J_e$ is convex in the random variable $\theta$, then higher uncertainty is likely to raise the marginal value of an emission, $e$. Of course, to completely characterize the response of $Y$ to $\sigma^2$, we need to solve (5). Nevertheless, when $|I_t|$ is small, the sign of $I_t$ is unlikely to affect the direction of the response of $Y$ to a higher $\sigma^2$.

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4 We also solved our model for a simpler information process, a discrete time process where full information about $\theta$ is obtained in period two. Although the intuition and the results are the same for the two processes of $\theta$, we are able to obtain complete analytical solutions for all three cases of transaction costs in the discrete time process. The results are available from the authors upon request.
Intuitively, the model is not much different from any static investment model where uncertainty affects the marginal value of the investment. If the marginal value function is convex in the underlying random variable, higher uncertainty raises the expected payoff of investment, no matter whether the optimal decision is to invest or to disinvest. That is, what determines the effects of uncertainty is the shape of the marginal benefit function, rather than the sign of $I_t$.

The discussion indicates that $I_t$ may change in the same direction as $\sigma^2$ increases, regardless of whether $I_t > 0$ or $I_t < 0$. Then uncertainty enhances policy persistence in one direction and reduces it in the opposite direction. For example, if higher uncertainty raises the marginal value of pollution $J_e(\theta, e)$, then more pollution should be allowed, resulting in a bigger increase in $e_t$ if $I_t > 0$ or a smaller decrease in $e_t$ if $I_t < 0$. In this case, high initial standards become more persistent than low ones: the agency is more willing to raise the standard than to lower it. Thus, uncertainty enhances policy persistence in one direction and weakens it in the other direction.

3. Asymmetric transaction costs

When the policy trend has already been set, the regulator can only change the standard in the direction of the trend. When new information calls for such a change, she will be reluctant to make the entire change because it cannot be reversed if future new information proves that the change has been too much. On the other hand, she can always make the change later if the new information justifies such a change. That is, we expect more gradual changes than without the constraint of the policy irreversibility, and a typical policy path consists of a sequence of small adjustments, rather than a few instances of large changes. Suppose the policy trend has not been set, but will be once the standard is changed. Then the regulator will be even more reluctant to change the policy, since not only she cannot reverse the change in face of any new information, but she will be setting a trend that restricts any future policy changes. Particularly strong information will induce her to change the current policy. In this case, the policy path involves a big change initially, followed by subsequent small adjustments.

To solve for the government’s optimal policy, we employ the logic of Pindyck (1988) and focus on the efficient marginal unit of emissions. In particular, given that $B''(\cdot) < 0$ and $d''(\cdot) > 0$, if in any period, given $\theta$, it is optimal to emit the $x$th unit of the pollutant, it must also be optimal to emit all of the $y$th units, for $y < x$. Therefore, we only need to identify the last unit of the pollutant that should be emitted. If the agency is indifferent between emitting this unit and waiting for more information, then all earlier units should be emitted and no more units should be emitted. The current emission is then compared with and adjusted to equate with this optimal emission level, if the required adjustment is allowed by the policy trend.

3.1. Optimal policy under pre-set trend

We call the policy trend a polluting trend if the emission standard can only increase, and a cleaning trend if the emission standard can only decrease. Consider first the polluting trend.
Suppose the current damage coefficient is $\theta$ and the emission rate is $e$, and the authority is deciding whether or not to raise the rate by one unit. If the emission standard is raised, one unit of emission will be added in all future periods since the policy cannot be reversed. Then the expected present value of the added net benefit over all future periods is

$$
d_v^P(\theta) = E_\theta \int_0^\infty e^{-rt}[B'(e) - \theta d'(e)] \, dt = \frac{B'(e)}{r} - \frac{\theta d'(e)}{r - \alpha},$$

(6)

where (1) is substituted for $\theta_t$. In (6), superscript “p” denotes the polluting trend, and subscript “0” denotes changing standard in the current period.

If the authority waits for $dt$ periods, she will observe the new value of $\theta$ at $t + dt$, and decide whether or not to raise the emission. Let $d_v^P(\theta)$ be the expected added value of waiting, given $\theta$, where subscript “1” denotes waiting (and possibly changing the policy in later periods). Applying dynamic programming and Ito’s Lemma to $d_v^P(\theta)$, we know $d_v^P(\cdot)$ satisfies

$$
\frac{1}{2}\sigma^2\theta^2 \, d_v^{PP}(\theta) + \alpha \theta \, d_v'(\theta) - r \, d_v(\theta) = 0,
$$

(7)

where the (single and double) primes stand for the (first and second order) derivatives with respect to $\theta$. As shown in Dixit and Pindyck (1994), the solution to (7) is

$$
d_v^P(\theta) = A_1 \theta^{\beta_1} + A_2 \theta^{\beta_2},
$$

(8)

where $A_1$ and $A_2$ are two constants to be determined by the boundary conditions, and $\beta_1 > 1$ and $\beta_2 < 0$ are the two solutions to the fundamental quadratic:

$$
\frac{1}{2}\sigma^2 \beta (\beta - 1) + \alpha \beta - r = 0.
$$

(9)

We can show that $\beta_1$ decreases and $\beta_2$ increases in the uncertainty level of $\theta$, $\sigma^2$.

If $\theta = \infty$, the emission causes too much damage and the proposed increase in the standard will never be adopted. Then $d_v^P(\theta)$ is the relevant measure of the agent’s payoff, but since the standard will never be raised (or changed), the expected added payoff from waiting is zero. Thus $d_v^P(\infty) = 0$, which implies that $A_1 = 0$. To determine $A_2$ and the critical $\theta^P$ at which the authority is indifferent between increasing the standard and waiting, we use the value matching and smooth pasting conditions, $d_v^P(\theta^P) = d_v^P(\theta^P)$ and $d_v^P(\theta^P) = d_v^P(\theta^P)$:

$$
A_2(\theta^P)^{\beta_2} = \frac{B'(e)}{r} - \frac{\theta^P d'(e)}{r - \alpha},
$$

(10)

$$
A_2 \theta^P(\theta^P)^{\beta_2 - 1} = - \frac{d'(e)}{r - \alpha}.
$$

(11)

Solving (10) and (11), we obtain

$$
\theta^P(e) = \frac{\beta_2}{\beta_2 - 1} \frac{B'(e)/r}{d'(e)/(r - \alpha)}, \quad A_2 = \frac{B'(e)}{r(1 - \beta_2)(\theta^P(e))^{\beta_2}}.
$$

(12)

Note that $d_v^P(\theta)$ is decreasing and linear and $d_v^P(\theta)$ is decreasing and convex in $\theta$. If the observed damage coefficient $\theta$ is high and falls in the “continuation” region, i.e. $\theta \geq \theta^P(e)$, $d_v^P(\theta)$ dominates $d_v^P(\theta)$ and the agency should not raise $e$ (i.e. it should wait). If, however,
the damage is low so that \( \theta < \theta^p(e) \), \( d\theta^p_\theta(\theta) \) is the relevant measure of value, and the agency should raise \( e \) (Fig. 3). As \( e \) is raised, \( \theta^p(e) \) decreases because \( B''(e) < 0 \) and \( d''(e) > 0 \). Thus when the observed damage coefficient \( \theta \) is lower than \( \theta^p(\theta) \), the standard \( e \) should be increased until \( \theta^p(e) = \theta \). Fig. 1 graphs \( \theta^p(e) \) and a sample policy path: starting at point \( A \), whenever the observed pollution damage coefficient \( \theta \) decreases, the standard \( e \) should be increased so that \( \theta^p(e) \) is reduced to the level of the current \( \theta \). If, however, \( \theta \) increases and is above \( \theta^p(e) \), the policy remains unchanged.

Since \( \beta_2 \) is negative and increasing in \( \sigma^2 \), we know \( \beta_2/(\beta_2 - 1) < 1 \) and decreases in \( \sigma^2 \). Without uncertainty, the optimal policy is given by \( \theta^*(e) = B'(e)/r/d'(e)/(r - \alpha) > \theta^p(e) \). Thus when the current \( \theta \in (\theta^p(e), \theta^*(e)) \), the standard is not raised even though it should be without the irreversible policy trend. In this case, in response to the future irreversibility, the authority becomes more cautious, and the existing policy becomes more persistent. Higher uncertainty reduces \( \theta^p(e) \), or enhances persistence of the current policy. From Fig. 1, we see that if the \( \theta^p(e) \) curve shifts down, it is more likely that the current policy is not changed, and if changed, the change will be at a smaller scale.

By definition, the polluting trend implies one form of policy persistence: the standard cannot be reduced even when new information calls for such a reduction. What we have shown is that this type of transaction cost leads to policy persistence even along the trend. The difference is that along the trend, the persistence is due to the regulator’s precaution. This persistence can take two forms. When the current \( \theta \) is between \( \theta^*(e) \) and \( \theta^p(e) \), the standard is not raised even though new information calls for more emissions. When \( \theta < \theta^p(e) \), the standard is increased, but at a smaller scale than without the policy trend.

Fig. 1. Optimal policies under pre-set trends.
Under the cleaning trend, suppose the current damage coefficient is $\theta$ and the emission level is $e$, and consider the decision of reducing the standard by one unit. The expected present value of the added benefit of adopting the policy now is
\[
d_v^c(\theta) = \theta d'(e) - \frac{B'(e)}{r} - \alpha - B'(e) r,
\]
where superscript “c” stands for the cleaning trend. The expected added value of waiting, $d_v^c(\theta)$, satisfies the following differential equation:
\[
\frac{1}{2} \sigma^2 \theta^2 d_v^c''(\theta) + \alpha \theta d_v^c'(\theta) - r d_v^c(\theta) = 0.
\]
The solution of (14) is $d_v^c(\theta) = D_1 \theta^\beta_1 + D_2 \theta^\beta_2$ where $\beta_1 > 1$ and $\beta_2 < 0$ are the two roots of (9). If $\theta = 0$, the pollution causes no damage and the proposed reduction will never be adopted. If we wait until the next period, no action will be undertaken. The expected added (or marginal) value of waiting is zero: $d_u^c(0) = 0$ which implies that $D_2 = 0$. From the value matching and smooth pasting conditions, we obtain $D_1 = B'(e)/(r(\beta_1 - 1))(\theta^\beta_1)$, and the critical level $\theta^c$:
\[
\theta^c(e) = \frac{\beta_1}{\beta_1 - 1} \frac{B'(e)/r}{d'(e)/(r - \alpha)},
\]
where $\beta_1 > 1$ and is decreasing in $\sigma^2$. The concavity of $B(\cdot)$ and convexity of $d(\cdot)$ implies that $\theta^c(e)$ is decreasing in $e$.

Eq. (15) implies the following decision rule: given any realization of $\theta$, if the current standard level is such that $\theta > \theta^c(e)$, the emission standard should be reduced so that the new critical $\theta$ equals $\theta$. If the current standard level is sufficiently low such that $\theta^c(e) > \theta$, the standard is not changed. Fig. 1 shows $\theta^c(e)$ and a sample policy path starting at point B. Again, without uncertainty, the optimal policy is given by $\theta^*(e) = (B'(e)/(r(\beta_1 - 1)(\theta^\beta_1))) < \theta^c(e)$, where the inequality follows because $\beta_1 > 1$. As $\sigma^2$ increases, both $\beta_1/(\beta_1 - 1)$ and $\theta^c(e)$ increase. Higher uncertainty enhances the policy persistence.

Fig. 2 shows the effects of uncertainty on the two critical values $\theta^p(e)$ and $\theta^c(e)$, for a given level of the current standard $e$. They start at the same level $\theta^*(e)$ when $\sigma = 0$, and $\theta^p(e)$ decreases while $\theta^c(e)$ increases as $\sigma$ rises. The arrows indicate allowed policy changes under each trend, or changes in $\theta^p$ or $\theta^c$ due to the policy changes. Even though the regulatory agency has the same payoff function, its optimal policies are different due to the different directions of policy rigidity and future learning. For example, if the starting condition is at point A, the standard should be raised until $\theta^p(e)$ moves down to pass A under the polluting trend, and should not be changed under the cleaning trend. If the starting condition is at B, the standard should not be changed under either trend. Note that higher uncertainty, by raising $\theta^c(e)$ and reducing $\theta^p(e)$, leads to an increased likelihood that the current policy is not changed, and a smaller scale of change if the change does occur. In summary,

**Remark 1.** Transaction costs in the form of an existing policy trend lead to policy persistence in two ways. First, due to the trend in the current period, the standard cannot be changed against the trend even when new information calls for such a change. Second, due to the trend in future periods, policy persistence occurs even along the trend. The regulator,
being cautious, chooses either to delay a change or to reduce its scale when a change does occur. Higher uncertainty increases the persistence along the policy trend.

The policy path is continuous in time. There may be many periods when the policy is not changed, either because the preferred change is against the policy trend, or because the authority is cautious enough not to change the policy along the trend. The changes, if they do occur, are of small scales. The reason is that there is no direct transaction cost in changing the policy along the trend. The policy path may involve jumps, or periodic changes of bigger scales, if there are direct costs, in particular if the costs are not convex (e.g., when there is fixed costs). This occurs since bigger scale changes can economize on such direct transaction costs. Our results indicate the incentive of the regulator in enacting small changes due to policy irreversibility, rather than direct costs. That is,

**Remark 2.** With an existing policy trend, the policy path is continuous.

### 3.2. Optimal trend-setting policy

Suppose currently a policy trend does not exist, but the new standard, if different from the current one, will set a trend that cannot be reversed. This may be the case if a long-standing policy is to be changed. Given a current standard $e$, if the government raises it by one unit, the policy trend will be a polluting trend, and the standard raised cannot be reversed. Then the (marginal) expected net payoff is $d\nu_p'(\theta)$, as defined in the last section. Similarly, if the government reduces the standard by one unit, the (marginal) expected payoff is $d\nu_c'(\theta)$. Using the same procedure in deriving (7) and (8), the expected payoff of waiting is given by

$$d\nu_w(\theta) = F_1\theta^{\beta_1} + F_2\theta^{\beta_2};$$

(16)
where $F_1$ and $F_2$ are two constants to be determined that are independent of $\theta$ (but depend upon $e$).

Let $\tilde{\theta}_p(e)$ be the critical $\theta$ level for a given $e$ such that the agency is indifferent between increasing the standard from $e$ and waiting, and $\tilde{\theta}_c(e)$ be the indifference level between decreasing from $e$ and waiting. Then value matching and smooth pasting conditions are

\begin{align}
\frac{d}{d\theta} \tilde{\theta}_p^0(\tilde{\theta}_p) &= d_{wv}(\tilde{\theta}_p); \quad \frac{d}{d\theta} \tilde{\theta}_p'(\tilde{\theta}_p) = d_{wv}'(\tilde{\theta}_p) \quad (17) \\
\frac{d}{d\theta} \tilde{\theta}_c^0(\tilde{\theta}_c) &= d_{wv}(\tilde{\theta}_c); \quad \frac{d}{d\theta} \tilde{\theta}_c'(\tilde{\theta}_c) = d_{wv}'(\tilde{\theta}_c) \quad (18)
\end{align}

The functions in (17) and (18) are well behaved and we expect that a unique solution exists. However, the equations cannot be solved analytically. We use a graphical approach to illustrate the solution. The expected benefits of acting now ($d_{v_p}^0(\theta)$ and $d_{v_c}^0(\theta)$) are the same with and without the pre-set policy trend. The only difference between the scenarios with and without the trend lies in the expected benefit of waiting. The benefit of waiting is higher without the pre-set trend: at least, the agency can “pretend” that a trend exists and act accordingly, in which case the benefit of waiting is the same as that under the pre-set trend. That is, we expect that $d_{wv}(\theta) \geq d_{v_p}^0(\theta)$ and $d_{wv}(\theta) \geq d_{v_c}^0(\theta)$. Then, as shown in Fig. 3, $\tilde{\theta}_p(e) \leq \theta_p(e)$, and $\tilde{\theta}_c(e) \geq \theta_c(e)$.

Fig. 3 is drawn for a particular level of $e$. It says that if the observed $\theta$ is lower than $\tilde{\theta}_p(e)$, that is, if the pollution damage is rather low, the emission standard should be increased. Since the increase immediately sets a polluting trend, the standard should be increased all the way to a level such that the associated $\theta_p(e)$, rather than $\tilde{\theta}_p(e)$, equals the current
observed $\theta$. Similarly, given $e$, if the observed pollution damage is sufficiently high so that $\theta > \tilde{\theta}$, the emission standard should be reduced to a level such that $\theta^p(e)$, rather than $\theta^c(e)$, equals the current $\theta$. The current policy should not be changed if the $\theta$ value falls between $\theta^p(e)$ and $\theta^c(e)$. Note that the range of $\theta$ on which the current policy is not changed is larger than under a pre-set trend. The agency is even more reluctant to change the current policy if the change leads to a new trend that cannot be reversed.

Unlike the case of a pre-existing policy trend, the policy path is discontinuous at the first instant of a policy change. To see this, suppose currently $e_0$ and $\theta_0$ are such that $\theta^p(e_0) = \theta_0$. Suppose in the next several moments, $\theta$ decreases from $\theta_0$. Under a polluting trend, in each moment the standard $e_0$ should be raised to a new level so that $\theta^p(e)$ equals the new $\theta$. The policy path is continuous due to the constant small increases in $e$. However, before the trend is set, the standard is not changed unless $\theta$ decreases enough to a level at or below $\tilde{\theta}$. When $\theta$ does fall below $\tilde{\theta}$, the standard should jump up from $e_0$ to a level such that $\theta^p(e)$ equals the current $\theta$.

In fact, there is always a discontinuous jump in the standard at the moment of the initial change. The reason is that the critical levels of $\theta$ determining whether the regulator would change the policy, $\theta^p(e_0)$ and $\theta^c(e_0)$, are different from the critical levels determining the actual emission standards when the changes do occur, $\theta^p(e_0)$ and $\theta^c(e_0)$. When new information arrives such that $\theta_t$ is close to $\theta^p$ or $\theta^c$, the policy is not changed because the regulator is very cautious due to the trend-setting effect of the new policy. Only when the evidence is sufficiently strong (i.e. when $\theta_t$ is below $\tilde{\theta}$) will the regulator make the change. However, once the regulator decides to change the standard, her caution about trend-setting disappears, and new policy needs to “undo” all the inertia accumulated when she was waiting for the strong evidence. That is, the discrete jump in the standard must be enough to move $\theta^p(e)$ or $\theta^c(e)$ through the distance $\theta^p(e_0) - \tilde{\theta}$ or $\theta^c(e_0) - \tilde{\theta}$. In this regard, the regulator acts as if there is a fixed cost of initially changing the policy. In summary,

Remark 3. Transaction costs in the form of trend-setting policy changes lead to more policy persistence than pre-existing policy trends. The persistence become more severe as uncertainty increases. When a change does occur, the scale of the change is determined as if the policy trend already exists. Consequently the policy path is discontinuous at the initial moment of policy change, and is continuous afterwards.

4. Policy implications and discussion

Since the seminal work of Coase (1960), economists have understood that the presence of transaction costs affects the efficient emission levels. In this paper, we demonstrate that the consequences of such transaction costs are more complex than static models depict. Specifically, an explicit dynamic formulation indicates that current and future transaction costs associated with changing a policy can augment or mitigate the static effects of transaction costs alone. The dynamic effects can take the form of not changing policies when it would be optimal to do so in the absence of transaction costs as well as in making smaller changes than would be efficient without transactions costs.
In particular, we investigate three scenarios based on alternative political economy stories that differ in the specific forms of transaction costs. We formally model each case to investigate how the presence of these transaction costs alters the efficient timing and scale of emission standards. In each case, the transaction costs generate a form of policy persistence: either slowing the efficient change in emission standards or reducing the size of that change.

We studied irreversible policy trends, while practically any trend is reversible at a sufficiently large cost. A more realistic scenario is that the cost of changing policies along a trend is lower than the cost of changing policies against the trend. While it would be interesting to extend our paper to this scenario, the major intuition we obtained remains valid. Particularly, the regulatory agency will continue to be cautious in changing policies along a pre-existing trend, and will be more so when the new policy sets a trend.

These results have important implications concerning how slowness to change, or the small steps in which policy change are made, are to be interpreted. Policy persistence may be a rational reaction by forward-looking policy makers to future transaction costs, rather than an inefficient outcome of the current political process.

While far from conclusive, the very different experiences seen in the lead phase-out program relative to local water quality control and the respective transaction costs associated with them may be instructive in understanding the empirical consequences of the transaction costs. Specifically, the lead phase-out program is often cited as an exemplary environmental program. The phase-out was completed in a timely manner (through 1980s), the environmental goal was met (lead out of gasoline) and there were few delays. In contrast, total maximum daily load (TMDL) regulations were established in the Clear Water Act of 1977 and may be one of the longest examples of policy persistence: despite the passage of 25 years, few water quality standards (TMDLs) have even been set, and much less significant improvements in water quality observed.

Part of the explanation may be due to the very different transaction costs associated with the potential policy changes between the two cases. In the case of lead, there was little doubt that the damages from lead in gasoline were significant; thus, the likelihood of changing the standard in the future was small. Consequently, there was little reason to delay setting the standard to reduce future transaction costs. In contrast, the benefits and costs of local water quality regulation are unknown, many actors are involved in making policy at the local level, and the optimal water quality standards are site specific thereby requiring many actions. The prospect for renegotiating standards over time is large. As a result, policy persistence is more likely to occur than in the case of lead, where there was little risk of facing significant future transaction costs.

Another implication of these results is that policy makers should pay close attention to future information and the potential costs associated with changing standards once they are set. To whatever extent possible, the authority should make attempts to reduce future transaction costs associated with changing standards. If there are no (or small) transaction costs associated with changing a policy in the future, the regulatory authority is free to use the best information available today to set the standards, without worrying that when new information becomes available, he will be unable to easily change the standard. This suggests that rules or institutions that make it more difficult to change future policies should be avoided. In this context, the ability of citizens to sue the EPA might be a source
of increased transaction costs which could discourage the desired flexibility in standard setting.  

A final case in which understanding policy persistence and transaction costs may be particularly valuable is global climate change. Given the degree of uncertainty regarding the damages resulting from changes in the carbon cycle, it is rational for policy makers to assume that new information will arrive over time that would suggest a different efficient standard. If committing to regulatory paths, such as the Kyoto Protocol, would increase the transaction costs associated with deviating from that path if the science warrants it (in either direction), it may be optimal to maintain flexibility by not committing more than necessary.

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References


5 There may be other efficiency-enhancing features of citizen suits that outweigh this potential disadvantage.

6 Of course, there may be important countervailing benefits from such commitments that are not reflected in a model focusing on transaction costs.