Centre for Climate Change Economics and Policy

Grantham Research Institute on Climate Change and the Environment

Political competition, learning and the consequences of heterogeneous beliefs for long-run public projects

Antony Millner, Hélène Ollivier and Leo Simon

January 2013

Centre for Climate Change Economics and Policy Working Paper No. 122

Grantham Research Institute on Climate Change and the Environment Working Paper No. 104

The Centre for Climate Change Economics and Policy (CCCEP) was established by the University of Leeds and the London School of Economics and Political Science in 2008 to advance public and private action on climate change through innovative, rigorous research. The Centre is funded by the UK Economic and Social Research Council and has five inter-linked research programmes:

1. Developing climate science and economics
2. Climate change governance for a new global deal
3. Adaptation to climate change and human development
4. Governments, markets and climate change mitigation
5. The Munich Re Programme - Evaluating the economics of climate risks and opportunities in the insurance sector

More information about the Centre for Climate Change Economics and Policy can be found at: http://www.cccep.ac.uk.

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training in climate change and the environment. The Institute is funded by the Grantham Foundation for the Protection of the Environment and the Global Green Growth Institute, and has five research programmes:

1. Global response strategies
2. Green growth
3. Practical aspects of climate policy
4. Adaptation and development
5. Resource security

More information about the Grantham Research Institute on Climate Change and the Environment can be found at: http://www.lse.ac.uk/grantham.

Political competition, learning, and the consequences of heterogeneous beliefs for long-run public projects

WORKING PAPER DRAFT

Antony Millner*[1], Hélène Ollivier[2], and Leo Simon[3]

[1]Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science

[2]CNRS, University of Paris I

[3]Department of Agricultural and Resource Economics, University of California, Berkeley

January 29, 2013

Abstract

An incumbent political party, who cares only about voters' welfare, faces future political competition from a similarly well-intentioned party whose beliefs about the consequences of a 'long-run' public policy are different from its own. We show that when the incumbent can endogenously influence whether learning occurs (active learning), future political competition gives her an incentive to distort her policy choices so as to reduce uncertainty and disagreement in the future. This incentive pushes all incumbents' policies in the same direction. We demonstrate this mechanism in a two period model of the regulation of a stock pollutant that combines the literature on uncertainty and learning in intertemporal choice with a simple model of political competition. If the interaction between active learning and political competition is strong enough, all incumbents, regardless of their beliefs, will emit more than they would like. Our model thus offers a candidate explanation for the weakness of long-run environmental policy in democracies that applies even in an ideal world in which politicians' objectives are aligned with voters'. The mechanism we identify is likely to apply in many long-run public policy contexts.

Many of the most important public policy problems democratic countries face have natural timescales significantly longer than the standard legislative term of four or five years, and require cumulative efforts by successive governments to be successfully managed. Consider, for example, environmental policy (in particular regulation of stock pollutants such as greenhouse gases), social security reform, sovereign debt management, and public infrastructure development. None of these issues can be successfully tackled in a single legislative term, and

*Email: `a.millner@lse.ac.uk`. We are grateful for helpful comments from...

the total quantity of resources devoted to them over time will likely be the result of decisions taken by several governments. As such, the policies incumbent politicians choose to address these issues are heavily influenced by the incentives the political system provides for them to make sound 'long-run' policy decisions, even if the effects of those decisions may only be realized once they have left office.

The literature has taken two approaches to studying the influence of politics on such long-run public projects. The first emphasizes inefficiencies that arise from the political opportunity costs of investments in public goods (many of which occur in static as well as dynamic settings), and relies on a stark divergence between the objectives of politicians and voters. Office seeking politicians cannot be rewarded for policy choices that benefit future voters, but are costly to present voters. In addition, the benefits of investments in long-run public goods are not easily observable in the present. Both of these effects can lead to myopic policy choices (Aidt & Dutta, 2007). Moreover, access to public goods is not easy to differentiate, and thus does not contribute to parties' political leverage. Hence, office-seeking politicians may prefer to focus on redistributive policies (Persson & Tabellini, 1999; Lizzeri & Persico, 2001; Acemoglu & Robinson, 2001), targeted policies that provide immediate benefits to blocks of voters or special interests (Bohn, 2007; Battaglini & Coate, 2008), or expanding public employment (Robinson & Verdier, 2002).

A second strand of literature emphasizes that the lack of future political control that is characteristic of democratic systems gives rise to incentives for incumbents to manipulate their current policy choices so as to influence both who gets elected in the future, and the policy choices future governments will make (Persson & Svensson, 1989; Aghion & Bolton, 1990; Tabellini & Alesina, 1990; Milesi-Ferretti & Spolaore, 1994; Besley & Coate, 1998; Persson & Tabellini, 2000; Azzimonti, 2011). These strategic incentives exist even when parties' preferences coincide with the preferences of a group of voters, e.g. in models of partisan politics. Thus, even in an ideal world in which parties care only about voter welfare, heterogeneous policy preferences and lack of future political control can lead to policy choices that are distorted away from the incumbent's optimum. The studies that investigate these strategic effects all make use of *preference* heterogeneity to study political distortions to policy choice – parties are assumed to have intrinsically different preference parameters, which induce heterogeneous preferences over policies, and hence a strategic incentive for an incumbent to manipulate present policy choices given that her reelection is uncertain.

In this paper we also examine the effects of future political competition on present policy choice, but take a different tack from the previous literature, in that we focus on the effects of heterogeneity in *beliefs* on policy choice. At first sight this may seem a minor modification – parties with different beliefs about the consequences of policy choices will clearly have different preferences over policies, and this is all that is needed for distortions due to a future loss of political control to occur. However, while preference parameters are usually thought of as immutable primitives of economic models, beliefs are dynamic, and potentially endogenous – information revealed in the future allows voters and political parties to learn, and thus to update their policy preferences. Thus when voters and parties differ only in their beliefs, and the amount of information they receive is endogenous to policy choice (we refer to this as 'active learning'), incumbent parties can influence the degree of convergence between their policy preferences and those of their political opponents in the future. This effect is entirely absent when parties differ only in their preference parameters.

While heterogeneity in preference parameters undoubtedly accounts for some of the divergences between political parties' policy preferences, heterogeneity in beliefs is likely to be an equally important factor. Milton Friedman famously argued that "differences about economic policy among disinterested citizens derive predominantly from different predictions about the economic consequences of taking action...rather than from fundamental differences in basic values" (Friedman, 1966). More recently, public surveys in the US demonstrate a strong polarization in the beliefs of Democrats and Republicans about a variety of policy issues, including the likely causes and severity of climate change (Leiserowitz et al., 2012; Borick & Rabe, 2012). Moreover, a focus on beliefs places uncertainty – a key characteristic of long-run public projects – at the heart of our analysis. Given the empirical plausibility of belief heterogeneity, and the fact that it gives rise to new incentives for incumbents to distort their policy choices that are absent under preference heterogeneity, it seems useful to study its effects.

Our core contribution is to elucidate the interaction between belief heterogeneity, active learning, and political competition, and how this affects the level of investment in public goods (or bads) with uncertain deferred benefits (costs). Since our concern is specifically to understand how the interaction of these factors determines how incumbents respond to the inter temporal tradeoff inherent in such problems, we abstract from questions of taxation and redistribution, and consider a stylized model in which voters only differ in their beliefs about the benefits of the policy, and parties that represent the beliefs of groups of voters must decide only on the level of policy. We show that the interaction between active learning and political competition gives rise to a new incentive for incumbents to distort their policy choices. This incentive pushes incumbents to choose policies that increase their chances of resolving uncertainty in the future, regardless of their beliefs. The intuition behind this result is simple – since the preferences of parties with different *a priori* beliefs converge when learning occurs, incumbents avoid the welfare costs of future competitive elections by choosing policies that reduce disagreement in the future.

We demonstrate this mechanism in a two period model that combines the literature on inter temporal decision making under uncertainty and learning (Arrow & Fisher, 1974; Henry, 1974; Epstein, 1980; Ulph & Ulph, 1997; Gollier et al., 2000; Fisher & Narain, 2003), with a simple but flexible model of political competition (Wittman, 1973, 1983; Roemer, 2001). For concreteness we focus on an environmental policy problem in which an incumbent must decide on the aggregate level of emissions in the economy in the first period, given that her political opponent has different beliefs about the likely future damages from cumulative emissions, and she is not certain to be in power in the second period. We find plausible primitive conditions on the welfare functions in this model under which introducing active learning into the model pushes incumbents to increase their emissions more when they face political competition in the future than when they are certain to be in office in both periods. If learning is responsive enough to first period policy choices, the interaction between active learning and political competition can be strong enough to force *both* parties to choose first period emissions that are higher than they would like. Thus the mechanism provides a candidate explanation for the 'weakness' of long-run environmental policy.

Since our model makes very charitable assumptions about the objectives of political parties, who are assumed to care only about voters' welfare, this mechanism demonstrates that even in a near ideal world, the short-run nature of the democratic system can make it difficult to implement sound long-run policies. While these insights are framed in terms of a model of environmental policy, the mechanism they rely on is present much more broadly, and may be at play in many long-run public policy contexts. In all cases, the interaction between active learning and political competition pushes incumbents to 'do more' of an action that increases their chances of resolving uncertainty and disagreement in the future.

1 The Model

We consider a two period model in which an incumbent political party can set some policy variable that has current benefits to the economy as a whole, which are known, but future costs, which are uncertain. Our archetypal example is environmental policy. Consider the case of regulating the level of greenhouse gas emissions in the economy. Emissions provide current benefits to the economy, but future costs due to the increase in the stock of CO_2 concentrations, which causes economic damages from climate change. The magnitude of these future costs is however uncertain – there is substantial uncertainty about how much the climate will respond to increases in CO_2 concentrations, and how damaging the concomitant climate shifts will be to the economy. Moreover, voters and political parties have heterogeneous beliefs about how costly cumulative emissions will be in the second period. An uncertain parameter controls the relationship between emissions and second period welfare in our model, and parties' *a priori* beliefs are captured by the probabilities they assign to the values of this parameter. Other interpretations of the model are equally direct – we discuss these in the conclusions.

In order to understand how active learning, political competition, and their interaction affect the first period policies of an incumbent in this model, we consider two learning scenarios and two political scenarios: Under *passive learning*, parties learn the true value of the uncertain parameter before second period emissions levels are set with some exogenous probability. Under *active learning*, the probability of learning is assumed to be an increasing function of first period emissions, and can thus be endogenously influenced by the incumbent. Political variation in the model is introduced by contrasting an *individual optimum* case, in which the incumbent is guaranteed to be in power in both periods, with a *political competition* case in which parties fight a competitive election in the second period to decide whose policy will be implemented. Considering all combinations of ('learning' $\times$ 'politics') leads to four scenarios, and examining the differences between the optimal first period emissions in these four cases allows us to isolate the additional effects of active learning, political competition, and their interaction, on the policy choices of an incumbent.

1.1 Payoff structure

Assume that parties choose aggregate emissions levels in the economy in two periods, denoted by e_1, e_2 respectively. Throughout the paper we make use of a shorthand subscript notation for partial derivatives, for example $\frac{\partial^3}{\partial x^2 \partial y} W(x,y) := W_{xxy}$. In addition, partial derivatives with respect to e_1 and e_2 will simply be denoted by the subscripts 1 and 2 respectively.
The (certain) first period benefits of emissions are denoted by $U(e_1)$, where $e_1 \geq 0$, and we assume that

$$U_1 > 0, U_{11} \leq 0. \tag{1}$$

Second period welfare, denoted by $W(e_2|e_1,\lambda)$, depends on the chosen level of emissions in the second period $e_2 \geq 0$, on the legacy of realized first period emissions e_1, and on an uncertain parameter λ. We assume that:

$$W_{22} \leq 0 \tag{2}$$

$$W_\lambda < 0 \tag{3}$$

$$W_1 < 0 \tag{4}$$

$$W_{21} < 0 \tag{5}$$

$$W_{2\lambda} < 0 \tag{6}$$

(2) ensures that second period welfare is concave in second period emissions – we do not assume $W_2 > 0$, as the marginal benefits of second period emissions depend on the level of realized first period emissions, and may be negative if first period emissions were high enough. This reflects the 'stock' nature of many environmental problems. Throughout the paper, however, for the sake of simplicity, we assume that the irreversibility constraint $e_2 \geq 0$ is not binding, i.e. optimal second period emissions are interior. This restriction facilitates our analysis, but our results are not crucially dependent on it. It is also an empirically plausible assumption – it is highly unlikely that λ will be so large as to force optimal emissions to zero.

(3) implies that λ is a 'bad', i.e we prefer low λ to high λ. We can think of λ as a parameter that controls how damaging pollution is to the economy. (4) says that e_1, while beneficial in the first period, is costly in the second period – this is the source of the inter temporal tension in the model. The fact that the inequality in (4) is strict ensures that first period emissions are not totally reversible, i.e. all the negative effects of e_1 in the second period cannot by reversed by manipulating e_2. Both of the conditions (3) and (4) are not essential for our main results[1], but aid in the interpretation of the model. The implications of conditions (5–6), which are essential, will become clear below.

The uncertain parameter λ is assumed to take two possible values, a high value λ_H, for which emissions cause large economic damages, and a low value $\lambda_L < \lambda_H$, for which emissions cause small damages. Parties' beliefs about λ are represented by subjective probabilities $(q, 1-q)$ over the states (λ_L, λ_H). Thus the second period welfare of a party with subjective beliefs $(q, 1-q)$ over the states (λ_L, λ_H) is given by

$$A(e_2|e_1, q) := qW(e_2|e_1, \lambda_L) + (1-q)W(e_2|e_1, \lambda_H), \tag{7}$$

and we define

$$A^*(e_1, q) := \max_{e_2 \geq 0} \left[qW(e_2|e_1, \lambda_L) + (1-q)W(e_2|e_1, \lambda_H)\right] \tag{8}$$

$$e_2^*(e_1, q) := \operatorname{argmax} \left[qW(e_2|e_1, \lambda_L) + (1-q)W(e_2|e_1, \lambda_H)\right]. \tag{9}$$

Similarly, if the party knows for sure what the realized value of λ will be, its second period welfare is

$$W^*(e_1, \lambda) := \max_{e_2 \geq 0} W(e_2|e_1, \lambda). \tag{10}$$

It is readily shown (see Appendix D) that the conditions (5) and (6) imply respectively that $e_2^*(e_1, q)$, is *decreasing* in e_1, and *increasing* in q. Thus, the more first period emissions occur, the less parties want to emit in the second period, and similarly, the greater the weight they put on the low damages state λ_L, the more they emit in the second period.

An example of a function W that satisfies the conditions (2–6) is:

$$W(e_2|e_1, \lambda) = B(e_2) - \lambda C(e_1 + e_2) \tag{11}$$

where the benefit of current emissions $B(e_2)$ satisfies $B' > 0, B'' < 0$, and the cost of cumulative emissions $C(e_1 + e_2)$ satisfies $C' > 0, C'' > 0$. We will use this functional form below as a simple illustration of our model, but will also prove results for much more general functions W that only satisfy the conditions (2), and (5–6).

[1] Theorem 1 below does not require these conditions.

1.2 Two learning scenarios

We will be interested in the effect of learning on first period policy choices, and will contrast two learning scenarios. Assume that with probability $f(e_1)$, parties learn the true value of λ in the second period, while with probability $1 - f(e_1)$ they learn nothing, where $f(e_1) \in [0,1], f' \geq 0$. This stark learning model allows us to capture the core interactions we are interested in in the simplest possible manner. The fact that we allow the probability of learning to depend on the level of first period emissions is crucial to the rest of the paper. The two learning scenarios we contrast correspond to the following choices for $f(e_1)$:

$$\text{Passive learning: } f(e_1) = f_0, \text{ a constant.} \tag{12}$$

$$\text{Active learning: } f(e_1) = f_0 + \tilde{f}(e_1) \tag{13}$$

where $\tilde{f}(0) = 0, \tilde{f}' > 0, \lim_{e_1 \to \infty} \tilde{f}(e_1) \leq 1 - f_0$.

Passive learning corresponds to a case in which information is revealed with some exogenous probability as time passes – this is the conventional case examined in the literature (e.g. Arrow & Fisher, 1974). We will use it as a baseline learning scenario.

Active learning captures the fact that for many public investments, the more of a given policy is enacted, the more is learned about the policy's consequences (see e.g. Prescott, 1972; Kelly & Kolstad, 1999; Karp & Zhang, 2006). Consider the case of greenhouse gas emissions. Much of the scientific uncertainty about the effects of increased CO_2 concentrations on global climate is irreducible *ex ante* – we simply do not have the data to narrow our uncertainty, as there is no comparable regime in the instrumental record in which CO_2 emissions increased as quickly, and as much, as they are now. Although climate models and observational data allow us to quantify our uncertainty in the climate's response to rapid anthropogenic forcing, that uncertainty range has remained largely unchanged over the last 40 years, despite considerable advances in climate modeling (Knutti & Hegerl, 2008). It is likely that the only way we will be able to reduce this uncertainty substantially is by observing the consequences of increased emissions, and the more we emit, the more we will learn. The case for active learning is also clear in many other large public projects – consider for example a policy which aims to decentralize control of educational decision making from a central ministry to individual schools. The larger the scale of such a program (i.e. the more schools or regions it includes), the more we learn about the causal effects of the policy on educational outcomes.

1.3 Heterogeneous beliefs and political competition

Suppose that there are two altruistic political parties, Green (G) and Brown (B), each with its own idiosyncratic value of q, and we assume, without loss of generality, that $q_G < q_B$. The parties are identical in their objectives, i.e. to maximize social welfare. But they disagree about q, the probability that λ will be low. Each party's beliefs are assumed to be representative of the beliefs of a set of voters.

The parties are dogmatic, in that they genuinely believe their value of q is the correct one today, and thus do not account for the other party's value of q in their welfare evaluations – they evaluate the welfare of the entire population (even those who disagree with them) using their own value of q. However, the parties are rational, and realize that in the future new observations or analyses may be realized that provide information about the value of λ. They will interpret this new evidence in the same, unbiased manner, and update their priors. Moreover, each party knows that the other party will do this. We compress this incremental learning process into a single period.

Figure 1 illustrates the timing of events in our model. At the beginning of the first period, an incumbent chooses an emissions level e_1. At the end of the first period the true value of λ is revealed (with probability $f(e_1)$), or nothing is learned about the value of λ (with probability $1 - f(e_1)$). In the case where learning occurs, parties' policy preferences are identical in the second period – there is no difference between them as they hold the same beliefs. There is thus a 'trivial' election – it doesn't matter who gets elected, as they would both choose the same policy. In the case where learning does not occur, parties beliefs are still divergent in the second period, and they must fight an election to decide whose policy gets enacted. Thus, at the beginning of the second period each party announces a platform (a level of emissions it commits to implementing in the second period), and voters decide between them in competitive elections. The platforms parties announce must thus account not only for the direct welfare benefits of the platform, but also for its 'electability'. Thus political

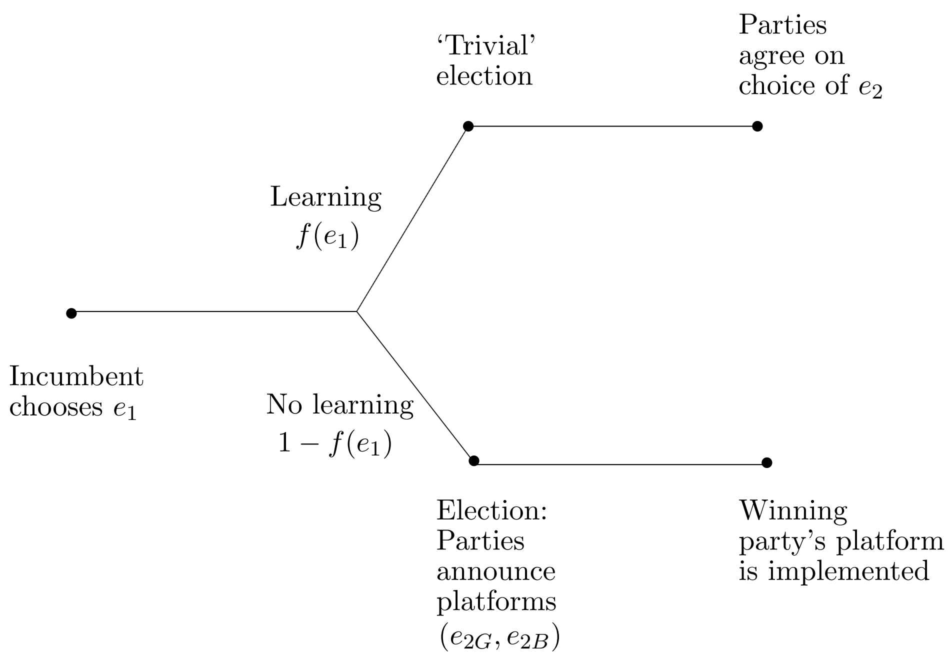

Figure 1: Timing of the political game.

competition induces parties to offer compromise platforms that balance the perceived benefits of the proposed policy with the chance of the party being elected. We model this electoral game using the Wittman model of political competition (Wittman, 1973, 1983; Roemer, 2001). Under the Wittman model, parties' second period payoffs are given by:

$$P^i(e_{2i}, e_{2j}|e_1) = \pi(e_{2i}, e_{2j})A(e_{2i}|e_1, q_i) + (1 - \pi(e_{2i}, e_{2j}))A(e_{2j}|e_1, q_i) \tag{14}$$

where $i \neq j \in \{G, B\}$, $\pi(e_{2i}, e_{2j}) = 1 - \pi(e_{2j}, e_{2i})$ is the probability of party i being elected, and e_{2i}, e_{2j} are each party's 2nd period platforms if learning has not occurred. Clearly, in this case parties are required to make a tradeoff between increasing their chance of being elected (π) and having their policy enacted, and choosing a policy that maximizes their welfare (A). Roemer (2001) finds conditions that ensure that an equilibrium to the political game with payoffs (14) exists. These conditions are always satisfied for our model, and we will assume uniqueness as well[2]. We denote the value of the game to party $i \in \{G, B\}$ by

$$V^i(e_1) := P^i(\hat{e}_{2i}, \hat{e}_{2j}|e_1) \tag{15}$$

where $\hat{e}_{2i}, \hat{e}_{2j}$ are the equilibrium policies of Party i and j respectively. These will also depend on e_1 in general.
Thus if party i is the incumbent in period 1, its optimal policy is

$$\hat{e}_{1i} := \text{argmax}_{e_1 \geq 0} \left[U(e_1) + f(e_1)\left[q_i W^*(e_1, \lambda_L) + (1 - q_i)W^*(e_1, \lambda_H)\right] + (1 - f(e_1))V^i(e_1)\right], \tag{16}$$

where we use the ˆ symbol to denote quantities in the 'political competition' case. The corresponding first order condition is:

$$U'(e_1) = \hat{\Phi}_i(e_1), \tag{17}$$

where we define

$$\begin{aligned}\hat{\Phi}_i(e_1) :=& f'(e_1)[V^i(e_1) - q_i W^*(e_1, \lambda_L) - (1 - q_i)W^*(e_1, \lambda_H)] - \frac{dV^i(e_1)}{de_1} \\ &+ f(e_1)\left[\frac{dV^i(e_1)}{de_1} - q_i\frac{dW^*(e_1, \lambda_L)}{de_1} - (1 - q_i)\frac{dW^*(e_1, \lambda_H)}{de_1}\right].\end{aligned} \tag{18}$$

In order to isolate the effects of political competition on first period choices, we will contrast the optima under political competition with a baseline case in which the incumbent is guaranteed to be in power in both periods – we refer to this as the 'individual optimum' case. In

[2] This is guaranteed in the models for $\pi(e_{2i}, e_{2j})$ we consider in Sections 2 and 3 below.

this case, the optimal first period emissions of the incumbent $i \in \{G, B\}$ are given by

$$e_{1i}^* := \text{argmax}_{e_1 \geq 0} \left[U(e_1) + f(e_1) \left[q_i W^*(e_1, \lambda_L) + (1 - q_i) W^*(e_1, \lambda_H) \right] + (1 - f(e_1)) A^*(e_1, q_i) \right]. \tag{19}$$

where we use the * superscript to denote quantities that represent the individual optimum case. The corresponding first order condition is:

$$U'(e_1) = \quad \Phi_i^*(e_1), \tag{20}$$

where

$$\begin{aligned} \Phi_i^*(e_1) := & f'(e_1)[A^*(e_1, q_i) - q_i W^*(e_1, \lambda_L) - (1 - q_i) W^*(e_1, \lambda_H)] - \frac{dA^*(e_1, q_i)}{de_1} \\ & + f(e_1) \left[\frac{dA^*(e_1, q_i)}{de_1} - q_i \frac{dW^*(e_1, \lambda_L)}{de_1} - (1 - q_i) \frac{dW^*(e_1, \lambda_H)}{de_1} \right]. \end{aligned} \tag{21}$$

1.4 Effect of active learning and political competition on first period decisions

We have set up two dimensions of variation in our model – passive vs. active learning, and political competition vs. the individual optimum. Table 1 summarizes our notation for optimal first period policies in each of the four possible scenarios for learning and politics.
We are interested in the *additional* effects of active learning and political competition on first period policies, relative to the passive learning/individual optimum baselines. To get at these effects we need to examine the differences between the elements of Table 1. We are also interested in the *interaction* between active learning and political competition – this will require us to examine a difference in differences.
It will be useful in what follows to define two operators. For any functional $Y(f)$ of the probability of learning $f(e_1)$, define

$$\Delta_L Y(f) := Y(f_0) - Y(f_0 + \tilde{f}(e_1)). \tag{22}$$

This operator captures the change in Y when we move from passive learning ($f(e_1) = f_0$) to active learning ($f(e_1) = f_0 + \tilde{f}(e_1)$) – the subscript L stands for 'Learning'. Similarly, for any

Table 1: Notation for our four policy scenarios

	Passive learning	Active learning
Individual Optimum	$e_1^*(f = f_0)$	$e_1^*(f = f_0 + \tilde{f}(e_1))$
Political Competition	$\hat{e}_1(f = f_0)$	$\hat{e}_1(f = f_0 + \tilde{f}(e_1))$

functional $Y(V^i)$ that depends on the political equilibrium value function $V^i(e_1)$, define

$$\Delta_P Y(V^i) := Y(A^*(e_1, q_i)) - Y(V^i(e_1)). \tag{23}$$

This quantity represents the change in Y when we move from the individual optimum, in which second period payoffs are given by $A^*(e_1, q_i)$ when learning does not occur, to political competition, where 'no learning' second period payoffs are given by $V^i(e_1)$. The subscript P stands for 'Politics'.

Comparing policies in the same row in Table 1 gives us the effect of active learning. This effect is captured by $\Delta_L(e_1^*) = e_1^*(f = f_0) - e_1^*(f = f_0 + \tilde{f}(e_1))$ in the individual optimum, and by $\Delta_L(\hat{e}_1) = \hat{e}_1(f = f_0) - \hat{e}_1(f = f_0 + \tilde{f}(e_1))$ under political competition.

Similarly, comparing the policies in the same column in Table 1 gives us the effect of political competition on the optimal policy choices of an incumbent. When learning is passive this effect is captured by $\Delta_P(e_1(f = f_0)) = e_1^*(f = f_0) - \hat{e}_1(f = f_0)$. When learning is active the effect is captured by $\Delta_P(e_1(f = f_0 + \tilde{f}(e_1))) = e_1^*(f = f_0 + \tilde{f}(e_1)) - \hat{e}_1(f = f_0 + \tilde{f}(e_1))$.

Finally we are interested in understanding how the interaction between active learning and political competition affects the decisions of the incumbent. That is, we are interested in the additional effect of active learning on policy choice under political competition, over and above the effect active learning has in the individual optimum. This interaction effect is captured by $\Delta_P(\Delta_L(e_1)) = \Delta_L(e_1^*) - \Delta_L(\hat{e}_1)$. Very roughly mapping this 'difference-in-differences' into econometric language, one can think of the political competition case as the 'treatment', the individual optimum case as the 'control', and the move from passive to active learning as an exogenous 'policy change'. We want to understand the *additional* effect of this 'policy change' on the 'treatment' group, but in order to do so we must subtract off its effect on the 'control' group.

2 Endogenous political competition

In this section we examine a model of political competition in which the electoral outcome depends only on the platforms parties announce, and voters' policy preferences are known with certainty. Analytic results that characterize the effects of active learning, political competition, and their interaction, on first period policy choice are possible in this case.

We pin down the nature of the political competition in the model by specifying values for the probability of election function $\pi(e_{2i}, e_{2j})$ in (14). Recall that q denotes a subjective belief that the realized value of λ will be λ_L. We assume that there is a distribution of voters with different values of q in the population, and denote the cumulative distribution function for q by $F(q)$. The population is assumed to split into two disjoint sets according to their beliefs, and each parties' beliefs are assumed to be representative of the beliefs of one of these sets[3].

[3]Note: This does not imply that all voters in a given set always vote for the party that represents the beliefs

$\pi(e_{2G}, e_{2B})$, the probability of the Green party (which has the lower value of q) winning the election, is modeled through:

$$\pi(e_{2G}, e_{2B}) = \begin{cases} 1 & \text{if } \Gamma(e_{2G}, e_{2B}) > 0.5 \\ 0.5 & \text{if } \Gamma(e_{2G}, e_{2B}) = 0.5 \\ 0 & \text{if } \Gamma(e_{2G}, e_{2B}) < 0.5 \end{cases} \tag{24}$$

where

$$\Gamma(e_{2G}, e_{2B}) := F(\{q : A(e_{2G}|e_1, q) > A(e_{2B}|e_1, q)\}) \tag{25}$$

is the measure of the set of voters who prefer policy e_{2G} to policy e_{2B}. Clearly, the probability of Brown winning the election is given by $1 - \pi$.

We have obtained a general result that allows a characterization of the relationships between the entries in Table 1 in this case. To begin we define

$$\epsilon_{x|y} := \text{Elasticity of } W_{2x} \text{ with respect to } y. \tag{26}$$

Theorem 1. *If the following conditions on W hold,*

$$\epsilon_{2|2} \geq \epsilon_{1|2} \tag{27}$$

$$\epsilon_{1|\lambda} > \epsilon_{2|\lambda} \tag{28}$$

the probability of election $\pi(e_{2i}, e_{2j})$ is given by (24), and $U''' \leq 0$, then

1. $\Delta_L(e_1^*) < 0$*: Active learning* ***increases*** *first period emissions (relative to passive learning) in the individual optimum for both parties.*

2. $\Delta_L(\hat{e}_1) < 0$*: Active learning* ***increases*** *first period emissions (relative to passive learning) under political competition, for both parties.*

3. $\Delta_P(e_1(f = f_0)) > 0$*: When learning is passive, political competition* ***reduces*** *first period emissions relative to the individual optimum, for both parties.*

4. $\Delta_P(\Delta_L(e_1)) > 0$*: Active learning always increases first period emissions* ***more*** *under political competition than in the individual optimum, for both parties.*

The consequences of the conditions on the elasticities $\epsilon_{x|y}$ in this theorem clearly require investigation. We will get to this immediately after the proof of the result. To fix ideas however, it may be useful to see what they imply for the simple functional form for W in

---

of that set.

(11). Substitution of (11) into (27) and (28) shows that these two conditions reduce to

$$-\frac{B'''}{B''} \leq -\frac{C'''}{C''}, \tag{29}$$

$$B'' < 0 \tag{30}$$

respectively. Thus the first condition requires the marginal costs of emissions C' to be more concave than their marginal benefits B'. The second condition is satisfied by assumption, so adds no additional restrictions. Notice that the first condition is always satisfied when both B and C are quadratic functions. We will exploit this fact to give an explicit parametric example of Theorem 1 in Section 2.1. Some readers may wish to skip ahead to this example, before returning to the proof.

We break the proof of Theorem 1 down into four lemmas. Our first lemma relates changes in the right hand side of the first order conditions Φ induced by active learning or political competition to the sign of the difference between optimal first period policies under different scenarios:

Lemma 1. *Assume that solutions to the first order conditions for e_1 in Table 1 exist and are unique in all cases. Then for any Φ,*

$$\Delta_L(\Phi) > (<) 0 \; \forall e_1 \Rightarrow \Delta_L(e_1) < (>) 0 \tag{31}$$

Similarly, for any f,

$$\Delta_P(\Phi) > (<) 0 \; \forall e_1 \Rightarrow \Delta_P(e_1) < (>) 0 \tag{32}$$

Moreover, if

1. *$U'''(e_1) \leq 0$*
2. *$\hat{e}_1(f = f_0) \leq e_1^*(f = f_0)$*
3. *$\Delta_P(\Delta_L(\Phi)) < 0 \; \forall e_1$*

Then $\Delta_P(\Delta_L(e_1)) > 0$.

Proof. See Appendix A □

From this lemma we see that we are going to be interested in the quantities $\Delta_L(\Phi^*(e_1))$,$\Delta_L(\hat{\Phi}(e_1))$, $\Delta_P(\Phi)$ and $\Delta_P(\Delta_L(\Phi))$. Examining the expressions (21) and (18), some simple calculations show that

$$\begin{aligned} \Delta_L(\Phi^*(e_1)) = & -\tilde{f}'(e_1)[A^*(e_1, q) - qW^*(e_1, \lambda_L) - (1-q)W^*(e_1, \lambda_H)] \\ & -\tilde{f}(e_1)\left[\frac{dA^*(e_1, q)}{de_1} - q\frac{dW^*(e_1, \lambda_L)}{de_1} - (1-q)\frac{dW^*(e_1, \lambda_H)}{de_1}\right] \end{aligned} \tag{33}$$

and

$$\Delta_L(\hat{\Phi}(e_1)) = -\tilde{f}'(e_1)[V^i(e_1) - q_i W^*(e_1,\lambda_L) - (1-q_i)W^*(e_1,\lambda_H)] \\ - \tilde{f}(e_1)\left[\frac{dV^i(e_1)}{de_1} - q_i\frac{dW^*(e_1,\lambda_L)}{de_1} - (1-q_i)\frac{dW^*(e_1,\lambda_H)}{de_1}\right] \tag{34}$$

Similarly, substitution from (21) and (18) shows that:

$$\Delta_P(\Phi) = f'(e_1)(A^*(e_1,q_i) - V^i(e_1)) - (1-f(e_1))(dA^*(e_1,q_i)/de_1 - dV^i(e_1)/de_1). \tag{35}$$

From this expression, we see that:

$$\text{Passive learning: } \operatorname{sgn}[\Delta_P(\Phi)] = -\operatorname{sgn}\left[dA^*(e_1,q_i)/de_1 - dV^i(e_1)/de_1\right] \tag{36}$$

$$\text{Active learning: } \operatorname{sgn}[\Delta_P(\Phi)] = \operatorname{sgn}\left[\frac{f'(e_1)}{1-f(e_1)} - \frac{dA^*(e_1,q_i)/de_1 - dV^i(e_1)/de_1}{A^*(e_1,q_i) - V^i(e_1)}\right], \tag{37}$$

where in the second line we have used the fact that $A^*(e_1,q_i) - V^i(e_1)$ is always positive. This follows from (14), which implies that $V^i(e_1)$ is a convex combination of two terms, each of which is less than or equal to $A^*(e_1,q_i)$.

Finally, the 'difference-in-differences' $\Delta_P(\Delta_L(e_1))$ will be controlled by the quantity $\Delta_P(\Delta_L(\Phi))$, given by

$$\Delta_P(\Delta_L(\Phi)) = [\Phi^*(f=f_0) - \Phi^*(f=f_0+\tilde{f}(e_1))] - [\hat{\Phi}(f=f_0) - \hat{\Phi}(f=f_0+\tilde{f}(e_1))] \\ = -\tilde{f}'(A^*(e_1,q_i) - V^i(e_1)) - \tilde{f}\left(\frac{dA^*}{de_1} - \frac{dV^i}{de_1}\right) \tag{38}$$

The second step of the proof uses Lemma 1 and the expressions (33–38) to show that two properties of the functions $A^*(e_1,q)$ and $V^i(e_1)$ are sufficient for the conclusions in Theorem 1:

Lemma 2. *Suppose that*

1. $\frac{dA^*(e_1,q)}{de_1} \leq q\frac{dW^*(e_1,\lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1,\lambda_H)}{de_1}$ *for all* q.
2. $dV^i(e_1)/de_1 < dA^*(e_1,q_i)/de_1$, *for both* $i \in \{G,B\}$.
3. $U'''(e_1) \leq 0$.

Then the four conclusions of Theorem 1 are implied.

Proof. The result follows by inspection of the four quantities (33–38), and Lemma 1. See Appendix B for the proof. □

It is worth noting that the directions of the two conditions in this lemma are the only ones that ensures that the signs of the quantities $\Delta_L(\Phi^*)$, $\Delta_L(\hat{\Phi})$, $\Delta_P(\Phi)$ (under passive learning), and $\Delta_P(\Delta_L(\Phi))$ are all known simultaneously. If $\frac{dA^*(e_1,q)}{de_1} > q\frac{dW^*(e_1,\lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1,\lambda_H)}{de_1}$, or $dV^i(e_1)/de_1 > dA^*(e_1, q_i)/de_1$, at least one of these quantities would have ambiguous sign. The third step of the proof shows that the value of the political game $V^i(e_1)$ has a simple form in this model:

Lemma 3. *Let the median voter's beliefs be $q_m = F^{-1}(1/2)$, and assume that $q_G < q_m < q_B$. The equilibrium outcome of the political game in which parties' payoffs are given by (14) and the probability of election is given by (24) consists in both parties proposing the optimal policy of the median voter, $e_2^*(e_1, q_m)$. Thus the value of the political game to party i is given by*

$$V^i(e_1) = A(e_2^*(e_1, q_m)|e_1, q_i). \tag{39}$$

Proof. See Appendix C. □

Thus when political competition is given by the model in (24), parties' platforms converge completely in the second period – they both offer the median voter's optimal policy[4].
The final crucial step of the proof uses the expression for $V^i(e_1)$ obtained in Lemma 3, and the conditions on W in Theorem 1, to show that the conditions in Lemma 2 are satisfied:

Lemma 4. *If the conditions (27–28) on W hold, and the value of the political game $V^i(e_1)$ is given by (39), then*

1. $\frac{dA^*(e_1,q)}{de_1} \leq q\frac{dW^*(e_1,\lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1,\lambda_H)}{de_1}$ *for all q.*
2. $dV^i(e_1)/de_1 < dA^*(e_1, q_i)/de_1$, *for both $i \in \{G, B\}$.*

Proof. See Appendix D □

Combining Lemma 4 with Lemma 2 and the condition $U''' \leq 0$, we arrive at Theorem 1.

2.1 A parametric example with linear marginal benefits and costs

As an example of the application of Theorem 1, we will now examine an explicit parametric example with linear marginal benefits and costs of emissions. This model has also been used by Ulph & Ulph (1997), who refer to it as 'the simplest model of global warming'.
Let

$$\tilde{B}(x) = b_1 x - \frac{b_2}{2}x^2$$
$$\tilde{C}(x) = \frac{c}{2}x^2$$

[4]The median voter equilibrium is also the equilibrium that would result if parties maximized their probability of election, and not the welfare of voters whose beliefs they represent as in (14). This was demonstrated in the classic work of Downs (1957). However, although the equilibrium in the Wittman model with probability of election given by (24) coincides with the Downsian equilibrium, parties' valuations of the equilibrium differ in our model, as shown in (39), whereas they coincide in the Downsian model. We consider a richer model of political competition that also permits divergence between parties' equilibrium platforms in Section 3.

where $b_1, b_2, c > 0$, and set

$$U(e_1) = \tilde{B}(e_1) \tag{40}$$

$$W(e_2|e_1, \lambda) = \tilde{B}(e_2) - \lambda\tilde{C}(e_1 + e_2). \tag{41}$$

As we showed above, the conditions (27–28) of Theorem 1 reduce to (29–30) for this model, and are thus identically satisfied in this quadratic case. Thus we can safely infer that the conclusions of Theorem 1 hold – active learning always increases emissions for both parties under political competition and in the individual optimum, but the increase in emissions is greater under political competition than in the individual optimum.

Theorem 1 thus shows that the interaction between active learning and political competition acts to increase emissions in this simple model. Recall however that under the conditions in Theorem 1, political competition reduces first period emissions relative to the individual optimum when learning is passive. The theorem is not however decisive as to the sign of $\Delta_P(e_1(f = f_0 + \tilde{f}(e_1)))$, i.e. the absolute effect of political competition on policy choice when learning is active. In particular, the question remains as to whether the interaction between active learning and political competition can be strong enough to lead to an *increase* in first period emissions relative to the individual optimum, thus overturning the corresponding result for passive learning. The following proposition shows that this is possible.

Proposition 1. *Let the learning function $f(e_1) = f_0 + (1 - f_0)(1 - e^{-\gamma e_1})$, and consider the quadratic model (40–41) . If $\gamma > 2b_2/b_1$, then first period emissions are* ***greater*** *under political competition than in the individual optimum for both parties.*

Proof. Second period welfare W is linear in λ in the quadratic model, so defining $\lambda(q_i) := q_i\lambda_L + (1 - q_i)\lambda_H$, it follows that

$$A(e_2|e_1, q_i) = q_i W(e_2|e_1, \lambda_L) + (1 - q_i)W(e_2|e_1, \lambda_H) = W(e_2|e_1, \lambda(q_i)), \tag{42}$$

$$A^*(e_1, q_i) = W^*(e_1, \lambda(q_i)). \tag{43}$$

We can readily solve for the second period policy $e_2^*(e_1, q_i)$ that maximizes $A(e_2|e_1, q_i) = W(e_2|e_1, \lambda(q_i))$:

$$e_2^*(e_1, q_i) = \max\left[\frac{b_1 - \lambda(q_i)ce_1}{b_2 + \lambda(q_i)c}, 0\right], \tag{44}$$

and we assume that the parameters of the problem are such that the irreversibility constraint is not binding, so the 'zero' solution never occurs. Moreover, since the conditions of Theorem 1 are satisfied, we know that

$$\begin{aligned} V^i(e_1) &= A(e_2^*(e_1, q_m)|e_1, q_i) \\ &= W(e_2^*(e_1, q_m)|e_1, \lambda(q_i)) \end{aligned} \tag{45}$$

Substitution[5] of (44) into (43) and (45) reveals that

$$A^*(e_1, q_i) - V^i(e_1) = \frac{c^2(\lambda(q_i) - \lambda(q_m))^2(b_1 + b_2 e_1)^2}{2(b_2 + c\lambda(q_i))(b_2 + c\lambda(q_m))^2} \tag{46}$$

Substituting this result and the expression for the learning function $f(e_1)$ into (37), we see that $\Delta_P(\Phi) > 0$ for *both* Green and Brown parties if:

$$\forall e_1 > 0, \ \gamma > \frac{2b_2}{b_1 + b_2 e_1}. \tag{47}$$

Remarkably, the quadratic structure and the median voter equilibrium have allowed us to simplify the highly complex second term in (37) down to an expression that is independent of the beliefs of the parties (q_i) and the median voter (q_m), the cost parameter (c) and the values of λ (λ_L and λ_H), and depends only on e_1 and the parameters of the benefit function $\tilde{B}(x)$. Since by Lemma 1 we require the inequality (47) to be satisfied for all e_1 in order to be sure that $\Delta_P(e_1(f = f_0 + \tilde{f}(e_1))) < 0$, we must ensure that γ is larger than the maximum value of the right hand side of (47), i.e. $\gamma > \frac{2b_2}{b_1}$. □

When the condition on γ in Proposition 1 is satisfied, political competition *increases* first period emissions relative to the individual optimum, for *both* parties. Thus this result overturns the passive learning case, in which we found that political competition reduces first period emissions relative to the individual optimum. The condition $\gamma > 2b_2/b_1$ has some intuitive appeal. The parameter γ controls how responsive the probability of learning is to increases in first period emissions. The larger is γ, the greater the interaction effect between active learning and political competition, and we know that this interaction leads to increases in first period emissions through our result on the 'diff-in-diff', which says that active learning increases first period emissions more under political competition than it does under the individual optimum. The condition determines a threshold value for γ that is sufficient to ensure that the interaction between active learning and political competition is strong enough to overcome the decrease in emissions that arises from political competition when learning is passive. Remarkably, this condition is sufficient to ensure this result for *both* parties.

2.2 Interpretation of Theorem 1

The conditions in Theorem 1 have two core consequences. First, they ensure that when learning is passive *both* parties reduce their emissions under political competition, relative to their individual optima. Second, they ensure that the interaction between active learning and political competition acts as an incentive to increase emissions for both parties. Combining these two facts allowed us to show just how powerful the interaction between political competition and active learning can be. As we demonstrated in Proposition 1, active learning

[5] This is best done with a computer algebra package.

can reverse the direction of the effect of political competition on first period optima for both parties, so that if learning is active 'enough', political competition will cause both parties' emissions choices to exceed their individual optima. In this section we explain the intuition behind both these results.

Consider our first result – that political competition reduces both parties' emissions when learning is passive. At first sight this is a surprising finding. One might well expect that the Green party should want to decrease its first period emissions under political competition (relative to its individual optimum) to counter the fact that second period policies are effectively chosen by a median voter, who will over emit relative to Green's optimum. However the same intuition should have the opposite effect for the Brown party – it should want to *increase* its first period emissions relative to its individual optimum, to counter the fact that the median voter will under emit relative to his optimum.

Remarkably however, our results show that this intuition does not hold in a large number of relevant cases – as demonstrated, for example, in (29). The key reason for this is that our conditions (27–28) ensure that both parties have a *strategic* incentive to reduce e_1. Moreover, for the Brown party the strategic benefits to reducing e_1 dominate the direct loss it sustains from doing so.

To understand this, begin by noting that differences between party payoffs in the individual optimum and under political competition only arise in the sub game in which learning does not occur. Under passive learning, e_1 only has an effect on welfare in this sub game, and not on the chance of this sub game occurring. It's therefore clear that if we want to understand the effects of political competition on first period optima when learning is passive, we need to focus on how e_1 affects welfare in this sub game under our two political scenarios. This is the message of our expression (36), which via Lemma 1, ensures that understanding the difference between the marginal effect of e_1 on second period 'no learning' welfare under the two political scenarios is sufficient to rank the first period optima.

Under political competition e_1 has both a direct and a strategic effect on welfare in this sub game. It affects welfare directly through the dependence of A on e_1, and strategically through the dependence of the median voter's second period optimum on e_1. We consider each of these effects in turn.

To understand how the conditions of Theorem 1 determine the strategic interactions in our model, we begin by noting that a key step in the proof of Lemma 4 in Appendix D, was to show that the conditions (27–28) imply

$$\frac{d^2 e_2^*}{de_1 dq} > 0. \tag{48}$$

Recall that $q_G < q_m < q_B$. Hence, we know that

$$\frac{d}{de_1}\left[e_2^*(e_1, q_m) - e_2^*(e_1, q_G)\right] > 0 \tag{49}$$

$$\frac{d}{de_1}\left[e_2^*(e_1, q_B) - e_2^*(e_1, q_m)\right] > 0. \tag{50}$$

Now by the monotonicity of $e_2^*(e_1, q)$ in q, we also know that

$$e_2^*(e_1, q_m) - e_2^*(e_1, q_G) > 0 \tag{51}$$

$$e_2^*(e_1, q_B) - e_2^*(e_1, q_m) > 0 \tag{52}$$

Thus from the inequalities (49–50) and (51–52), we see that if we increase e_1, the distance between the median voters' optimum and either parties' optimum *increases*. However, reducing e_1 brings the median voters' optimum closer to each of the parties' individual optima. Since the median voters' optimum is the policy that is implemented under political competition (when learning does not occur), both parties want this policy to be as close to their individual optima as possible. Figure 2 illustrates this intuition graphically. The condition (48) thus ensures that both parties have a strategic incentive to reduce e_1 relative to their individual optimum.

Now consider the direct effect of a change in e_1 on welfare in the 'no learning' sub game. The direct effect of a marginal decrease in e_1 always improves second period welfare *more* under political competition that in the individual optimum for the Green party. However, the opposite is true for the Brown party. To see this, note that the facts that $A_{21} < 0$, and $e_2^*(e_1, q)$ is increasing in q, imply

$$A_1(e_2^*(e_1, q_m)|e_1, q_G) < A_1(e_2^*(e_1, q_G)|e_1, q_G) \tag{53}$$

$$A_1(e_2^*(e_1, q_m)|e_1, q_B) > A_1(e_2^*(e_1, q_B)|e_1, q_B). \tag{54}$$

A *reduction* in e_1 reverses the direction of these inequalities, giving the result. Thus, while the strategic interactions we identified above are sufficient to ensure that the Green party reduces her emissions, there are two competing effects for the Brown party, and we need to ensure that the strategic effect always dominates for this party. As we show in the Appendix D, the conditions of Theorem 1 ensure this. They guarantee that the *total* effect of a marginal reduction in e_1 is always greater under political competition than in the individual optimum (see equations (61–62)). This, via our expression (36), and Lemma 1, ensures that political competition reduces emissions for both parties when learning is passive.

Next, consider our second core finding, i.e. that active learning pushes incumbents – whether Green or Brown – to increase their emissions *more* under political competition than in their individual optimum. Active learning has a straightforward effect on first period emissions in the individual optimum of both parties. Because emitting more in the first period increases the chances of learning in the second period, and because more information is welfare beneficial, both parties increase their emissions under active learning, relative to the passive learning benchmark.

When incumbents face political competition in the second period the anticipated gains from learning are even larger than they were in the individual optimum. The reason for this is that when learning occurs, parties' policy preferences converge – they both hold the same beliefs, and thus would choose to implement the same policies. This is welfare improving to both parties, as competitive elections require each party to deviate from their individual optima in order to increase their chances of election. Thus, when learning is active, and incumbents can endogenously influence the degree of convergence between their second period policy preferences and those of their competitor's, they adjust their first period policies so as to increase the likelihood of convergence. The interaction between the two dimensions of variation in the model – active learning and political competition – thus pushes both parties

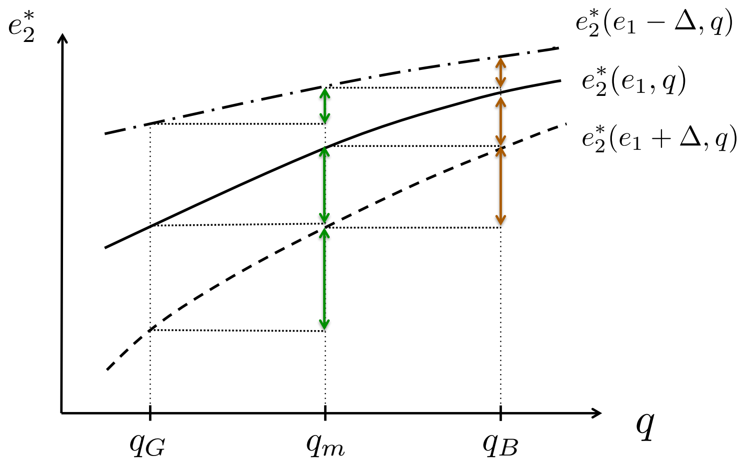

Figure 2: Strategic interactions between the first period choices of an incumbent and the second period choices of the median voter. The condition $\frac{d^2 e_2^*}{de_1 dq} > 0$ implies that for any $\Delta > 0$, the curves $e_2^*(e_1 + \Delta, q)$, $e_2^*(e_1, q)$ and $e_2^*(e_1 - \Delta, q)$ as functions of q are ordered as in the figure above. *Increasing* e_1 relative to the individual optimum of the incumbent party increases the difference between the second period optima of the median voter and the incumbent, regardless of whether the incumbent is Green or Brown. However, *decreasing* e_1 relative to the incumbent's individual optimum brings the median voter's second period optimum closer to the incumbent's, for both parties.

to ‘do more’ to reduce uncertainty in the future.

3 Alternative models of political competition

The model of political competition in Section 2 proved useful for obtaining analytical insights into the relationships between the four optimal first period policies in Table 1. It is however restrictive, in that the equilibrium policy choices of the two parties always coincide in this model – they both choose the median voter’s optimum. In this section we consider alternative models of political competition in which parties’ platforms can diverge in equilibrium. We show that the results we obtained in Section 2 can be extended to these models.

Our first model replaces the model of political competition in Section 2, in which the probability of election $\pi(e_{2i}, e_{2j})$ is determined endogenously, with a model in which π is an exogenous parameter that is independent of parties’ platforms. It is readily seen that in this case parties’ equilibrium platforms will coincide with their individually optimal policies – thus this case corresponds to an opposite extreme, in which parties platforms are maximally divergent in the political game. We have the following proposition in this case:

Proposition 2. *Suppose that the conditions on U and W in Theorem 1 are satisfied. Assume that the outcome of the political process is completely exogenously determined, so that $\pi(e_{2i}, e_{2j})$ is an arbitrary constant in $[0, 1]$. Then the conclusions of Theorem 1 continue to hold.*

Proof. See Appendix E. □

Thus, we know that the results in Section 2 hold at both political extremes, i.e. when the outcome of elections is completely endogenous, or completely exogenous. Appendix E shows that the effects at play in this result are exactly analogous to those we identified in Section 2.2, when discussing the interpretation of Theorem 1. This explains why the conditions we relied on in Theorem 1 are unchanged in this case. This result also shows that our findings extend to a model in which power is certain to change hands in the second period – simply set $\pi = 0$ for Green, or $\pi = 1$ for Brown, in Proposition 2. This is the case examined by e.g. Persson & Svensson (1989); Aghion & Bolton (1990).

It is natural to ask whether our results will continue to hold in an intermediate case, in which the outcome of the political process depends on both exogenous and endogenous factors, and parties’ platforms neither converge completely, nor are maximally divergent. In order to examine this case we consider a model of political competition due to Roemer (2001). Unlike the model for $\pi(e_{2i}, e_{2j})$ in (24), in this model political parties are not certain of the relationship between their announced platforms and the vote share they will receive. Parties’ vote shares are modeled as the sum of two terms – an endogenous term identical to that in (24), and an exogenous error term that represents parties' uncertainty about how their actions will map into electoral outcomes.

Recall that $\Gamma(e_{2G}, e_{2B})$, defined in (25), is the measure of the set of voters who prefer e_{2G} to e_{2B}. Let η be a random variable with

$$\text{Prob}(\eta \leq x) := H(x;\sigma) = \frac{1}{\sigma}\int_{-\infty}^{x} h\left(\frac{x'}{\sigma}\right) dx' \tag{55}$$

where $h(x)$ is an even, zero mean, probability density, and $H(x;\sigma)$ is the cumulative distribution function for η. The probability of Green winning the election in this model is defined to be:

$$\begin{aligned}\pi(e_{2G}, e_{2B}) &= \text{Prob}\left(\Gamma(e_{2G}, e_{2B}) + \eta > \frac{1}{2}\right) \\ &= 1 - H\left(1/2 - \Gamma(e_{2G}, e_{2B}); \sigma\right) \end{aligned} \tag{56}$$

This definition makes it clear that there are two terms that contribute to the electoral outcome – the endogenous term Γ that represents what parties know about voters' policy preferences, and the exogenous term η which represents parties' uncertainty about voters' behavior. The smaller is the width of the probability distribution for η, controlled by σ, the more the electoral outcome depends on the endogenous factor Γ. However as the width of the distribution for η increases the exogenous uncertainty in the electoral outcome begins to dominate, so that when $\sigma \to \infty$, Γ plays no role in determining the election outcome, and $\pi \to \frac{1}{2}$. Varying σ thus allows us to interpolate between the endogenous model of politics in Section 2, and the exogenous model of Proposition 2.

Analytic expressions for the value of the political game $V^i(e_1)$ in the model (56) are not possible at intermediate values of σ, so we simulate the model in an illustrative case, solving for the four optimal policies in Table 1. We pick the quadratic cost and benefit functions in (40–41), assume that voter's beliefs q are uniformly distributed on $[0, 1]$, and pick $h(x)$ to be the uniform distribution on $[-1, 1]$. Thus η is uniformly distributed on $[-\sigma, \sigma]$. We solve the model over a range of values for σ, and in two learning scenarios – one passive, the other active. Further details about the parameter values and learning function we employ, and our solution method, are in Appendix F.

Figure 3 summarizes our findings. The figure plots the difference between optimal first period emissions under political competition and in the individual optimum as a function of σ. The top panel corresponds to the passive learning case, and the bottom panel corresponds to the active learning case. The green (brown) curves assume that a Green (Brown) incumbent is in power in the first period. The figure shows that the directions of the effects we observed in Propositions 1 and 2 are preserved at intermediate values of σ. Political competition reduces emissions relative to the individual optimum for both parties when learning is passive.

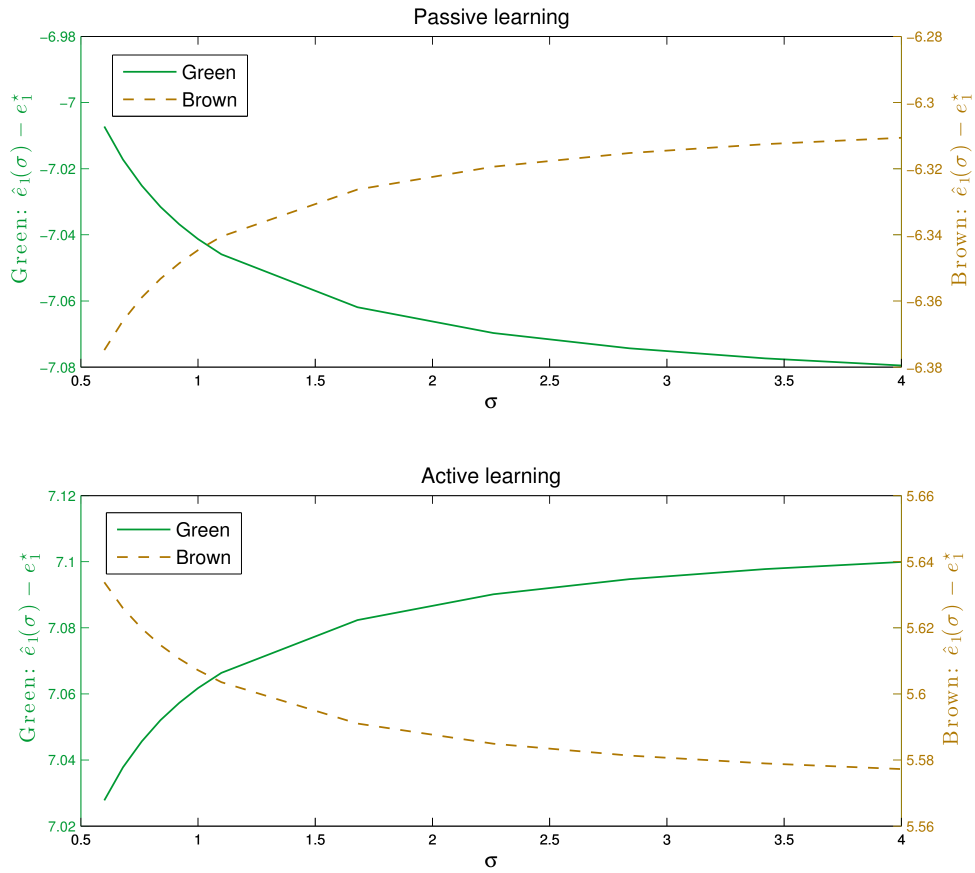

Figure 3: Difference between first period optima under political competition and in the individual optimum, as a function of σ. As $\sigma \to 0$, we reclaim the model of Section 2 in which political competition is purely endogenous and parties' second period platforms converge. As σ increases the effect of the exogenous error term in (56) on the outcome of the election increases, and parties' second period platforms diverge, approaching the case examined in Proposition 2.

However, when learning is active, optimal first period emissions exceed the individual optimum for both parties, and for all values of σ. Thus our core results – that the interaction between active learning and political competition forces the first period emissions of both parties upwards, and can make them exceed their individual optima – are demonstrated for a wide class of political dynamics.

4 Conclusions

Our analysis has shown that when beliefs are the primary source of disagreement between political parties, a new incentive for incumbents to manipulate their policy choices arises that is not present when parties only differ in their preference parameters. This stems from the interaction between active learning – the ability to endogenously influence future information revelation through current policy choices – and political competition. Active learning allows incumbents to control the degree of disagreement between parties in the future. Since the incumbent avoids a costly election with an opponent very different from herself if information is revealed and beliefs converge, she has an incentive to distort her policy choices so as to increase the chances of resolving uncertainty in the future, regardless of her initial beliefs.

We demonstrated this effect in a simple two period model of environmental policy with two political parties that hold different *a priori* beliefs about the dependence of second period welfare on cumulative emissions. We found plausible conditions on the welfare functions in our model under which: i) active learning increases first period emissions for both parties (relative to passive learning) whether they face political competition or not, ii) Political competition reduces the first period emissions of both parties (relative to the individual optimum) when learning is passive, iii) Active learning always increases emissions more under political competition than in the individual optimum for both parties, iv) If learning is 'active enough', the emissions of both parties under political competition will exceed their individual optima.

The mechanism we have identified applies to many other policy contexts. Consider for example a public investment project that requires us to sustain current costs for uncertain future benefits. Our results apply to this case with only trivial modifications to the technical details. Once again, incumbents have an incentive to invest more heavily in the project so as to resolve uncertainty and disagreement in the future. This shows that for some decisions our mechanism leads to more ambitious policy choices (e.g. invest in renewables to resolve disagreements about their costs and scalability), while for others it may lead to less (e.g. under abatement of greenhouse gases to resolve disagreements about climate science). Since the two decisions in this example both have consequences for a single policy issue, it is an empirical question as to which effect dominates policy choice. This parallels similar issues in the literature on irreversibility and climate policy, which shows that climate policy requires us to trade off two irreversibilities – abatement capital investments, and greenhouse gas accumulation (Kolstad, 1996). Understanding how political competition and active learning affect policy choice in this context requires a more complex model with explicit capital and environmental stocks, and would be a fruitful subject for future research.

A Proof of Lemma 1

To prove the first part of the lemma, note that when comparing any two solutions to the first order conditions (20) or (17), the left hand side is always given by the same decreasing function $U'(e_1)$. Thus, assuming that unique solutions exist, if the sign of the difference in the right hand sides, $\Delta_L(\Phi)$ or $\Delta_P(\Phi)$ as appropriate, is independent of e_1, we are be able to infer the sign of the difference in optimal policies, as illustrated by Figure 4 in the case of $\Delta_P(\Phi)$.

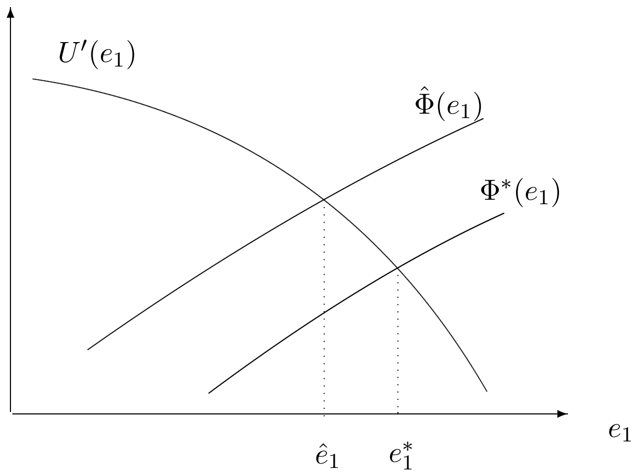

Figure 4: Effect of a change in the right hand side of the first order conditions induced by political competition on optimal first period policies.

To prove the second part of the lemma, consider Figure 5. Suppose that $\Delta_P(\Delta_L(\Phi)) = 0$, so that the change in the right hand sides of the FOCs induced by active learning is the same in the individual optimum and under political competition. Then the figure shows that the curvature of U', and the fact that $\hat{e}_1(f = f_0) < e_1^*(f = f_0)$ ensures that $\Delta_L(\hat{e}_1) > \Delta_L(e_1^*)$. The conditions of the proposition in fact guarantee that $\Delta_P(\Delta_L(\Phi)) < 0$, so the change in the right hand side of the FOC induced by active learning is *greater* under political competition than in the individual optimum. The result follows.

B Proof of Lemma 2

1. Consider $\Delta_L(e_1^*)$, which, via Lemma 1, is controlled by (33). By assumption, $\frac{dA^*(e_1,q)}{de_1} \leq q\frac{dW^*(e_1,\lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1,\lambda_H)}{de_1}$, which means that the second term in (33) is positive. It is also always true that

$$A^*(e_1, q) < qW^*(e_1, \lambda_L) + (1-q)W^*(e_1, \lambda_H) \tag{57}$$

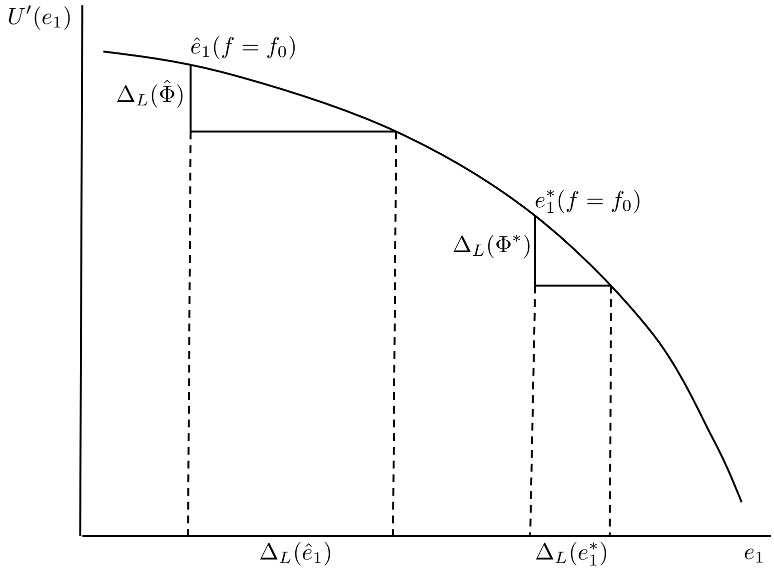

Figure 5: Illustration of the second result in Lemma 1

This follows from the fact that $A^*(e_1, q)$ is the upper envelope of a set of functions that is linear in $(q, 1-q)$, and is thus convex in this vector of probabilities (see e.g. Gollier, 2001, p. 359). It follows that $\Delta_L(\Phi^*(e_1)) > 0$, and hence $\Delta_L(e_1^*) < 0$.

2. Consider $\Delta_L(\hat{e}_1)$, the effect of active learning on emissions under political competition. This is controlled by $\Delta_L(\hat{\Phi}(e_1))$ in equation (34). We know that the first term in this expression in positive since $V^i(e_1) < A^*(e_1, q_i) < q_i W^*(e_1, \lambda_L) + (1-q_i)W^*(e_1, \lambda_H)$. By assumption, $dV^i(e_1)/de_1 < dA^*(e_1, q_i)/de_1 \leq q\frac{dW^*(e_1,\lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1,\lambda_H)}{de_1}$, so the second term in (34) is also negative. Hence $\Delta_L(\hat{\Phi}(e_1)) > 0$, and $\Delta_L(\hat{e}_1) < 0$.

3. Consider $\Delta_P(e_1(f=f_0))$, i.e. the effect of political competition under passive learning. The assumption $dV^i(e_1)/de_1 < dA^*(e_1, q_i)/de_1$ clearly implies that $\Delta_P(\Phi) < 0$ in this case, and hence, via Lemma 1, $\Delta_P(e_1(f=f_0)) > 0$.

4. Consider $\Delta_P(\Delta_L(e_1))$. Examine the expression for $\Delta_P(\Delta_L(\Phi))$ in (38). The first term is negative, and the assumptions of the proposition ensure that the second term in (38) is also negative, and hence $\Delta_P(\Delta_L(\Phi)) < 0$. We have also just shown that $\hat{e}_1(f=f_0) < e_1^*(f=f_0)$, and by assumption $U''' \leq 0$, so the conditions of Lemma 1 are satisfied, and we can conclude that $\Delta_P(\Delta_L(e_1)) > 0$.

C Proof of Lemma 3

This result is an application of a theorem due to Roemer (2001). Recall that in the second period, when no learning occurs, voters' preferences are given by $A(e_2|e_1, q)$, where e_2 is the policy variable, and q is the voters' type, which is distributed according to $F(q)$ in the population. We assume that parties' payoffs are given by (14), with the probability of election π given by (24), and the parties' values of q are in $\{q_G, q_B\}$.

Theorem (Roemer, 2001) *Assume that:*

1. *Voter preferences are continuous in q and e_2*
2. *Voter preferences are single peaked in e_2 for all q.*
3. *The set of voters who are indifferent between any two policies e_2 and e_2' has measure zero.*
4. *(Monotonicity) For every pair of policies e_2 and e_2' where $e_2 < e_2'$, there exists a policy e_2'' such that the set of voters who prefer e_2 to e_2' is equivalent to the set of voters whose optimal policies are less than e_2''.*
5. *$\Psi(x)$, the set of voters with optimal policies less than x, is continuous and strictly increasing*
6. *The median voter's optimal policy falls between the optimal policies of the parties.*

When conditions 1–6 are satisfied, the unique equilibrium of the game in which parties payoffs are given by (14) and the probability of election π is given by (24) consists of both parties playing $e_{2m} := e_2^*(e_1, q_m)$, where q_m satisfies $F(q_m) = 1/2$.

We need to check that the conditions of this theorem are satisfied for our model. Condition 1 is satisfied by assumption for our function A, and condition 2 follows from the assumption (2), i.e. $W_{22} < 0$. This implies that A is concave in e_2, and we have assumed that an interior optimum exists, hence A is single peaked in e_2. Condition 3 means that the distribution function $F(q)$ is continuous on $[0, 1]$, the space of types, and is a mild technical restriction. Conditions 4-5 both rely on the following fact in our model: The optimal policy $e_2^*(e_1, q)$ is a monotonic (in fact increasing) function of q. We have guaranteed this by assumption (i.e. the assumption $W_{2\lambda} < 0$ ensures it). To show monotonicity (condition 4), consider two policies e_2 and e_2', with $e_2 < e_2'$. A voter of type q prefers the former to the latter iff:

$$\begin{aligned}
&A(e_2'|e_1, q) > A(e_2|e_1, q) \\
&\Rightarrow qW(e_2'|e_1, \lambda_L) + (1-q)W(e_2'|e_1, \lambda_H) > qW(e_2|e_1, \lambda_L) + (1-q)W(e_2|e_1, \lambda_H) \\
&\Rightarrow q < N(e_2, e_2')
\end{aligned} \tag{58}$$

where N is a number which depends on the two policies. Now since the optimal policy function $e_2^*(q)$ is increasing in q, we can write the condition $q < N$ equivalently as $e_2^*(q) < e_2^*(N)$. But this condition is exactly of the form required for monotonicity, i.e. we have identified a policy $e_2^*(N)$ such that the set of voters who prefer e_2 to e_2' is equivalent to all those voters with optimal policies less than $e_2^*(N)$. Condition 5 follows from assuming $F(q)$ is continuous and that the optimal policies are monotonic in q. Finally, Condition 6 requires $q_G < q_m < q_B$, surely a reasonable assumption. Thus our model fits the conditions of the theorem, and the result it established.

D Proof of Lemma 4

We prove this proposition in stages, beginning with the second result:

$$\frac{d}{de_1} V^i(e_1) < \frac{d}{de_1} A^*(e_1, q_i) \text{ for both } i \in \{G, B\} \tag{59}$$

By Lemma 3, we have

$$V^i(e_1) = A(e_2^*(e_1, q_m)|e_1, q_i). \tag{60}$$

Define

$$R(q, q') := \frac{d}{de_1} A(e_2^*(e_1, q)|e_1, q'). \tag{61}$$

and consider the quantity

$$\Omega(q, q') := R(q, q') - R(q', q'). \tag{62}$$

For Party B, the inequality $dV^i/de_1 < dA^*(e_1, q_i)/de_1$ translates into $\Omega(q, q') < 0$ for some $q < q'$, while for Party G the inequality translates into $\Omega(q, q') < 0$ for some $q > q'$. Thus if we can find conditions that ensure

$$\Omega(q, q') < 0 \tag{63}$$

for all q we will be done. Suppose we knew that

$$\operatorname{sgn}\left(\left. \frac{dR(x, q')}{dx} \right|_{x=q} \right) = \operatorname{sgn}(q' - q). \tag{64}$$

By inspection, if this were true it would imply $\Omega(q, q') < 0$ regardless of whether $q < q'$ or $q > q'$. To see this, consider the case $q > q'$. If (64) holds, it implies that $R(q, q') < R(q', q')$, and hence $\Omega(q, q') < \Omega(q', q') = 0$. Similar reasoning holds for the case $q < q'$.
We are thus interested in computing

$$\frac{d}{dq} R(q, q') = \frac{d^2}{dq de_1} A(e_2^*(e_1, q)|e_1, q') \tag{65}$$

As a preliminary step, note that by definition,

$$A_2(e_2^*(e_1, q)|e_1, q) = 0 \tag{66}$$

Implicitly differentiating this identity with respect to e_1 and q respectively, we have,

$$\frac{de_2^*}{de_1} = -\frac{A_{21}}{A_{22}} \tag{67}$$
$$\frac{de_2^*}{dq} = -\frac{A_{2q}}{A_{22}} \tag{68}$$

By assumption (2), $A_{22} < 0$, and it is easily shown that assumptions (5) and (6) ensure that

$$A_{21} < 0 \tag{69}$$
$$A_{2q} > 0 \tag{70}$$

respectively. Hence the optimal policy $e_2^*(e_1, q)$ is decreasing in e_1 and increasing in q.
As a short hand, we will use the symbol A to refer to the function $A(e_2^*(e_1, q)|e_1, q)$, and A' will refer to the function $A(e_2^*(e_1, q)|e_1, q')$. Now,

$$\frac{d^2}{dqde_1} A(e_2^*(e_1, q)|q', e_1) \tag{71}$$
$$= \frac{d}{dq}\left(A'_2 \frac{de_2^*}{de_1} + A'_1\right) \tag{72}$$
$$= \left(A'_{22}\frac{de_2^*}{dq} + A'_{2q}\right)\frac{de_2}{de_1} + A'_2\frac{d^2e_2^*}{de_1dq} + A'_{21}\frac{de_2^*}{dq} + A'_{1q} \tag{73}$$
$$= \left(A'_{22}\frac{-A_{2q}}{A_{22}} + 0\right)\frac{-A_{21}}{A_{22}} + A'_2\frac{d^2e_2^*}{de_1dq} + A'_{21}\frac{-A_{2q}}{A_{22}} + 0 \tag{74}$$
$$= \frac{A_{2q}}{(A_{22})^2}\left(A'_{22}A_{21} - A_{22}A'_{21}\right) + A'_2\frac{d^2e_2^*}{de_1dq} \tag{75}$$

The factor in the round brackets in the first term is antisymmetric under the change of variables $q \leftrightarrow q'$, and thus changes sign at $q = q'$. The second term is proportional to A'_2 which also changes sign at $q = q'$. Thus the whole expression changes sign at $q = q'$ provided the coefficients that multiply the factors that are switching sign are of definite (and the same) sign, and provided the two factors that switch sign have the same (and not opposite) signs.
From (64), we want it to be the case that when $q < q'$, the whole expression in (75) is positive. Consider the first term in (75) – we want this to be positive when $q < q'$. The fact $A_{2q} > 0$, so we need the factor inside the brackets to be positive for $q < q'$, i.e.

$$q < q' \Rightarrow \frac{A'_{22}}{A'_{21}} > \frac{A_{22}}{A_{21}}. \tag{76}$$

A sufficient condition that ensures this is:

$$\Rightarrow \frac{\partial}{\partial q}\left(\frac{A_{22}}{A_{21}}\right) > 0 \tag{77}$$

$$\Rightarrow \frac{A_{22q}}{A_{22}} > \frac{A_{21q}}{A_{21}}. \tag{78}$$

Now consider the second term in (75). $A_2' > 0$ when $q < q'$ (this follows from $A_{22} < 0$, and from the monotonicity of e_2^* in q), so the second term will be positive if $\frac{d^2 e_2^*}{de_1 dq}$ is positive. We now look for conditions that ensure this is the case.

Recall that the optimal policy $e_2^*(e_1, q)$ satisfies (66). Implicitly differentiating (66) with respect to e_1 leads to an equation that defines $\frac{de_2^*}{de_1}$ in terms of e_2^*, e_1, and q. We then have:

$$\frac{d^2 e_2^*}{dq de_1} = \left(\frac{\partial}{\partial e_2^*}\frac{de_2^*}{de_1}\right)\frac{de_2^*}{dq} + \frac{\partial}{\partial q}\frac{de_2^*}{de_1} \tag{79}$$

Since $\frac{de_2^*}{dq} > 0$ by assumption, the following conditions ensure that $\frac{d^2 e_2^*}{de_1 dq} > 0$:

$$\frac{\partial}{\partial e_2^*}\frac{de_2^*}{de_1} > 0 \tag{80}$$

$$\frac{\partial}{\partial q}\frac{de_2^*}{de_1} > 0 \tag{81}$$

Using the fact that $\frac{de_2^*}{de_1} = -\frac{A_{21}}{A_{22}}$, these inequalities become,

$$\frac{A_{221}}{A_{21}} < \frac{A_{222}}{A_{22}} \tag{82}$$

$$\frac{A_{21q}}{A_{21}} < \frac{A_{22q}}{A_{22}} \tag{83}$$

The second of these inequalities is identical to (78), while the first inequality is a new condition. For convenience, denote $W^L := W(e_2|e_1, \lambda_L), W^H := W(e_2|e_1, \lambda_H)$. Consider the inequality

$$\frac{A_{22q}}{A_{22}} > \frac{A_{21q}}{A_{21}} \tag{84}$$

$$\Rightarrow \frac{W_{22}^L - W_{22}^H}{qW_{22}^L + (1-q)W_{22}^H} > \frac{W_{21}^L - W_{21}^H}{qW_{21}^L + (1-q)W_{21}^H} \tag{85}$$

$$\Rightarrow \frac{1}{W_{21}^L W_{21}^H}\left(\frac{W_{22}^L}{W_{21}^L} - \frac{W_{22}^H}{W_{21}^H}\right) > 0, \tag{86}$$

where the last line follows after two or three lines of algebra. For this inequality to be satisfied, it is sufficient for

$$\frac{\partial}{\partial\lambda}\frac{W_{22}}{W_{21}} < 0 \tag{87}$$

$$\Rightarrow \frac{W_{22\lambda}}{W_{22}} < \frac{W_{21\lambda}}{W_{21}} \tag{88}$$

Similarly, one can show that

$$\frac{W_{222}}{W_{22}} > \frac{W_{221}}{W_{21}} \Rightarrow \frac{A_{222}}{A_{22}} > \frac{A_{221}}{A_{21}}, \tag{89}$$

Thus, we have shown that (88) and (89) are sufficient to ensure $\Omega(q, q') < 0$ for all q, q', and hence the second part of the lemma is established. Simple manipulation of these inequalities shows that they can be written in terms of the elasticities $\epsilon_{x|y}$ in Theorem 1.
Now consider the first part of the lemma, which says that for any q,

$$\frac{dA^*(e_1, q)}{de_1} - \left(q\frac{dW^*(e_1, \lambda_L)}{de_1} + (1-q)\frac{dW^*(e_1, \lambda_H)}{de_1}\right) < 0. \tag{90}$$

Since

$$\frac{dA^*(e_1, q)}{de_1} = q\frac{dW(e_2^*(e_1, q)|e_1, \lambda_L)}{de_1} + (1-q)\frac{dW(e_2^*(e_1, q)|e_1, \lambda_H)}{de_1} \tag{91}$$

we can write the expression on the left hand side of (90) as

$$q\left[\frac{dW(e_2^*(e_1, q)|e_1, \lambda_L)}{de_1} - \frac{dW^*(e_1, \lambda_L)}{de_1}\right] + (1-q)\left[\frac{dW(e_2^*(e_1, q)|e_1, \lambda_H)}{de_1} - \frac{dW^*(e_1, \lambda_H)}{de_1}\right] \tag{92}$$

$$= q\left[\frac{dA(e_2^*(e_1, q)|e_1, 1)}{de_1} - \frac{dA^*(e_1, 1)}{de_1}\right] + (1-q)\left[\frac{dA(e_2^*(e_1, q)|e_1, 0)}{de_1} - \frac{dA^*(e_1, 0)}{de_1}\right] \tag{93}$$

$$= q\Omega(q, 1) + (1-q)\Omega(q, 0) \tag{94}$$

Since we have just found conditions that ensure $\Omega(q, q') < 0$ for arbitrary values of q and q', these conditions also guarantee that (90) is satisfied.

E Proof of Proposition 2

When political competition is exogenous, each parties' equilibrium policy is to offer its own individual optimum, so the value of the political game to party i is given by

$$V^i(e_1) = k_i A(e_2^*(e_1, q_i)|e_1, q_i) + (1-k_i)A(e_2^*(e_1, q_j)|e_1, q_i), \tag{95}$$

where k_i is some constant, and $k_i = 1 - k_j$. Thus,

$$\begin{aligned}\frac{d}{de_1}\left(A^*(e_1,q_i) - V^i(e_1)\right) &= (1-k_i)\frac{d}{de_1}\left(A(e_2^*(e_1,q_i)|e_1,q_i) - A(e_2^*(e_1,q_j)|e_1,q_i)\right) \\ &= -(1-k_i)\Omega(q_j,q_i) \\ &\geq 0 \end{aligned} \tag{96}$$

where the last inequality follows from the proof of Lemma 4. Thus the second condition in Lemma 2 continues to hold in this case, and we know from Lemma 4 that the conditions (27–28) on W ensure that the first condition in Lemma 2 also holds. Thus the result is established.

Note that this result relies crucially on the fact that our conditions on W ensure that $\Omega(q,q') \leq 0$ for any q, q'. This was precisely what was needed to prove Theorem 1, hence the same conditions are sufficient for our results is both cases.

F Details of numerical simulations in Figure 3

We picked the quadratic benefit and cost functions (40–41, and set the learning function $f(e_1)$ as follows:

$$f(e_1) = f_0 + \frac{2}{\pi}(1-f_0)\arctan(f_1 e_1) \tag{97}$$

Table 2 lists the parameters of the model, and the values we assumed to produce Figure 3. Plugging our assumptions that voters' beliefs q are uniformly distributed on $[0,1]$, and the error term η is uniformly distributed on $[-\sigma,\sigma]$ into (56), we find that the probability of the Green party being elected is

$$\pi(e_{2G}, e_{2B}) = \frac{\sigma + Y(e_{2G}, e_{2B}) - \frac{1}{2}}{2\sigma}, \tag{98}$$

Table 2: Parameters of the simulation results in Figure 3.

Parameter	Value
b_1	10
b_2	4
c	3
λ_H	5
λ_L	2
q_B	0.6
q_G	0.4
f_0	0.1
f_1 (Active)	1

where

$$Y(e_{2G}, e_{2B}) := \frac{1}{\lambda_H - \lambda_L}\left[\lambda_H - \frac{2b_1 - b_2(e_{2G} + e_{2B})}{c(2e_1 + e_{2G} + e_{2B})}\right]. \tag{99}$$

Plugging this expression for $\pi(e_{2G}, e_{2B})$ into (14) yields each parties' payoff function in the second period 'no learning' sub game. We solved numerically for the Nash equilibrium of this sub game as a function of first period policy e_1, thus determining the value of the game to party i, i.e. $V^i(e_1)$. We then used standard optimization routines to solve for the four optimal first period policies in Table 1, repeating this process for the range of σ values in Figure 3.

References

D. Acemoglu & J. A. Robinson (2001). 'Inefficient Redistribution'. *American Political Science Review* **95**(3):649–661.

P. Aghion & P. Bolton (1990). *Public debt management: theory and history*, chap. Government domestic debt and the risk of default: a political-economic model of the strategic role of debt, p. 315. Cambridge University Press.

T. S. Aidt & J. Dutta (2007). 'Policy myopia and economic growth'. *European Journal of Political Economy* **23**(3):734–753.

K. J. Arrow & A. C. Fisher (1974). 'Environmental Preservation, Uncertainty, and Irreversibility'. *The Quarterly Journal of Economics* **88**(2):312–319.

M. Azzimonti (2011). 'Barriers to Investment in Polarized Societies'. *The American Economic Review* **101**(5):2182–2204.

M. Battaglini & S. Coate (2008). 'A Dynamic Theory of Public Spending, Taxation, and Debt'. *The American Economic Review* **98**(1):201–236.

T. Besley & S. Coate (1998). 'Sources of inefficiency in a representative democracy: a dynamic analysis'. *American Economic Review* pp. 139–156.

F. Bohn (2007). 'Polarisation, uncertainty and public investment failure'. *European Journal of Political Economy* **23**(4):1077–1087.

C. Borick & B. Rabe (2012). 'Fall 2011 National Survey of American Public Opinion on Climate Change'. *Issues in Governance Studies, Brookings Institution* .

A. Downs (1957). *An economic theory of democracy.* New York: Harper Collins.

L. G. Epstein (1980). 'Decision Making and the Temporal Resolution of Uncertainty'. *International Economic Review* **21**(2):269–283.

A. C. Fisher & U. Narain (2003). 'Global Warming, Endogenous Risk, and Irreversibility'. *Environmental and Resource Economics* **25**(4):395–416.

M. Friedman (1966). 'The methodology of positive economics'. In *Essays in positive economics*. University of Chicago Press.

C. Gollier (2001). *The economics of risk and time*. MIT Press, Cambridge, Mass.; London.

C. Gollier, et al. (2000). 'Scientific progress and irreversibility: an economic interpretation of the 'Precautionary Principle''. *Journal of Public Economics* **75**(2):229–253.

C. Henry (1974). 'Investment Decisions Under Uncertainty: The "Irreversibility Effect"'. *The American Economic Review* **64**(6):1006–1012.

L. Karp & J. Zhang (2006). 'Regulation with anticipated learning about environmental damages'. *Journal of Environmental Economics and Management* **51**(3):259–279.

D. L. Kelly & C. D. Kolstad (1999). 'Bayesian learning, growth, and pollution'. *Journal of Economic Dynamics and Control* **23**(4):491–518.

R. Knutti & G. C. Hegerl (2008). 'The equilibrium sensitivity of the Earth's temperature to radiation changes'. *Nature Geoscience* **1**(11):735–743.

C. D. Kolstad (1996). 'Fundamental irreversibilities in stock externalities'. *Journal of Public Economics* **60**(2):221–233.

A. Leiserowitz, et al. (2012). 'Americans' knowledge of climate change'. `http://environment.yale.edu/climate/files/ClimateChangeKnowledge2010.pdf`.

A. Lizzeri & N. Persico (2001). 'The provision of public goods under alternative electoral incentives'. *American Economic Review* **91**(1):p. 225.

G. M. Milesi-Ferretti & E. Spolaore (1994). 'How cynical can an incumbent be? Strategic policy in a model of government spending'. *Journal of Public Economics* **55**(1):121–140.

T. Persson & L. E. O. Svensson (1989). 'Why a Stubborn Conservative would Run a Deficit: Policy with Time- Inconsistent Preferences'. *The Quarterly Journal of Economics* **104**(2):325.

T. Persson & G. Tabellini (1999). 'The size and scope of government:: Comparative politics with rational politicians'. *European Economic Review* **43**(4–6):699–735.

T. Persson & G. E. Tabellini (2000). *Political Economics: Explaining Economic Policy*. MIT Press.

E. C. Prescott (1972). 'The Multi-Period Control Problem Under Uncertainty'. *Econometrica* **40**(6):1043–1058.

J. Robinson & T. Verdier (2002). 'The political economy of clientelism'. *CEPR Discussion Paper* .

J. E. Roemer (2001). *Political Competition: Theory and Applications.* Harvard University Press.

G. Tabellini & A. Alesina (1990). 'Voting on the Budget Deficit'. *The American Economic Review* pp. 37–49.

A. Ulph & D. Ulph (1997). 'Global Warming, Irreversibility and Learning'. *The Economic Journal* **107**(442):636–650.

D. Wittman (1983). 'Candidate Motivation: A Synthesis of Alternative Theories'. *The American Political Science Review* **77**(1):142–157.

D. A. Wittman (1973). 'Parties as Utility Maximizers'. *The American Political Science Review* **67**(2):490–498.