# Environmental Regulation and Induced Innovation in the Presence of Policy Uncertainty

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**Abstract**

This paper examines the effectiveness and effects of government environmental policy in a model of induced innovation and policy uncertainty. Policy uncertainty is defined as the unwritten component of government policy that is revealed through observable gestures or rhetoric and relates to the apparent willingness of the government to follow through on policy promises or to enforce existing regulations. Firms observe these gestures by the government and form beliefs about the 'true' policy and act accordingly. From this framework the paper demonstrates that a government can increase current consumption while at the same time appearing to maintain a strong environmental policy through inaction or gestures that signal to firms an unwillingness to enforce current regulations. This behavior can be politically expedient in a democratic society because the current administration can reap the benefits of increased consumption while shifting the environmental costs to future administrations.

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**Environmental Regulation and Induced Innovation in the Presence of Policy Uncertainty**

The purpose of incentive regulation, by definition, is to provide a structure of positive and negative payoffs that create a framework in which individual firms, acting in their own best interest, behave in ways that are deemed desirable by the governing authority. This type of incentive structure is typically predicated on the belief that firms will respond to the newly created incentives as if they inhabited a world of certainty. However, the very nature of a democratic society, with its oft-replenished leadership and constantly changing policies, makes any regulatory structure inherently uncertain (e.g. Kolstad, 2002). Moreover, as firms expect changes in the future to current regulatory structures, they will base their decisions on the set of current regulations and their own *subjective* expectations of future regulatory design. Knowing this, governments can exploit this degree of policy uncertainty to alter the incentive structure and influence firm behavior through simple rhetoric that is meant to signal possible changes in future regulation (whether or not the government actually intends to follow through on these changes). This is especially true for the design of environmental policy, which is inherently dynamic and subject to a relatively large degree of policy uncertainty.

To formally demonstrate the effect policy uncertainty can have on the economy and the environment we construct a stylized general equilibrium model with an induced innovation component that determines the development of new abatement technologies (Goulder and Mathai, 2000; Grimaud, 1999; Bovenberg and Smulders, 1995). Within the context of this framework we postulate that a government's environmental policy is actually composed of two parts: First, there is a standard regulatory component of policy design that describes the actual set of regulations in place (e.g. a tax on pollution or emissions), which is directly observable. Second, there is the government's *announced environmental position* relative to the set of current regulations, which we refer to as the non-regulatory component of policy design. As a result of asymmetric information the populace is uncertain as to whether the government's announced environmental position, or rhetoric, is politically feasible. This implies that when a government's announced environmental position does not coincide with the current set of regulations there is 'policy uncertainty'.[1]

It is shown that this type of policy uncertainty can systematically affect the rate at which new abatement technologies are introduced to the economy. In particular, we show that if a government announces an environmental position in opposition to the current set of regulations, the effect on the economy and the environment is approximately the same as a change in the regulation itself. Consider the following scenario. Assume that the government (or political group) in power wants to weaken a current environmental regulation, say a pollution tax, but may not have the political capital or will to effect an actual change in the regulation, or enforcement, itself. Instead, the government simply uses rhetoric to announce an environmental plan to dismantle or challenge this environmental regulation in the future. This announcement by the government alters society's expectations over the continuation of the current environmental regulation, which in turn, causes firms to assign a higher probability to the discontinuation of the

[1] Our study relates to the political economy-trade literature which studies the role of government credibility and rhetoric in the design of trade policy (e.g. Calvo 1989; Rodrik, 1991, 1989), and the industrial organization literature on incentive regulation and commitment, which usually incorporates some sort of private information on the part of a monopolistic firm about their costs (e.g. Baron, 1985; Laffont and Tirole, 1993).

pollution tax at some time in the future. It then follows that firms reduce investment in the development of new abatement technologies because the expected payoff is now lower, which increases the resources available for general production and consumption.[2] In effect, the government can weaken current environmental policy by systematically altering society's perception of *future* regulation rather than going through the political process of changing the current regulation itself, the pollution tax, through rhetoric.[3]

After demonstrating the approximate equivalence between a change in a regulation and political rhetoric in presence of policy uncertainty we highlight three important properties of our stylized economy. The first two properties relate to policy and the third relates to data analysis. The first policy implication, as discussed in the preceding paragraph, suggests that a government can use rhetoric to 'steer' or guide the economy and the environment with roughly the same degree of precision as the more direct approach of changing the regulations themselves. As in the example, the government weakened environmental policy through political rhetoric, which (temporarily) increased production, consumption, and pollution in the economy without actually going through the regulatory process. This implies that if the government in power, and its constituency, has an environmental position that contrasts sharply with the actual set of regulations in place it can (temporarily) weaken these regulations with an appropriate use of rhetoric.

The second policy implication of the model is that policy uncertainty and the use of political rhetoric can affect the rate of development for new abatement technologies,

[2] It is just as easy to show that a government can strengthen environmental policy, but for reasons that will become clear, incentives exist that make a weakening of the policy more likely.

[3] Policy uncertainty is different than the uncertainty surrounding the impacts of pollution on the environment. This latter type of environmental uncertainty is studied in Kelly and Kolstad (1999) and Kolstad (1996), to sight a few, in the context of global warming and $CO^2$ emissions.

which in turn, can affect the cost associated with achieving an environmental target. This is in addition to the 'implementation effect', discussed in Isik (2004), where policy uncertainty can reduce the use of existing abatement technologies. Specifically, if the long-run environmental target or objective does not change, future administrations or generations must face a higher environmental tax (a more stringent environmental regulation), relative to the pre-rhetoric rate, if this environmental target is to be achieved. In addition, future consumption is reduced relative to its pre-rhetoric rate and future generations or administrations must bear a disproportionate amount of the cost of achieving the environmental objective.

The third implication of the model is statistical in nature. If policy uncertainty is present, which is the likely case, identical policies may appear to have different statistical effects on the variables of interest if we do not control for the government's environmental position and society's expectations. Specifically, the statistical relationship between a regulation and the economic or environmental variable of interest may convey little information about the 'true' effect of the regulation because of the omitted policy position variable. To illustrate this, imagine a pollution tax implemented by a previous government. A new government then announces a plan to eliminate this tax (without actually doing so). Exploration of the data may appear to show that the regulation did little to induce the development of new technologies, reduce pollution or reduce consumption. Thus, we may conclude based on the statistical relationship that the environmental regulation was ineffective. But, as we demonstrate in our model, this statistical relationship, or lack thereof, may be due to society's expectations and a more general environment policy, which includes the government's environmental position, not the ineffectiveness of the regulation itself.

There are two important assumptions in our model that we wish to discuss here in the introduction. The first, and perhaps most important, is that in a world of policy uncertainty the government can in fact steer or guide expectations through its use of political rhetoric. Specifically, it is assumed that there exists a well-defined expectations function that maps the government's announced environmental position into society's subjective probability distribution over future regulatory design. This stylized framework allows the government to 'pick' the transition path of the economy and environment for a given set of regulations. The second is that the government's environmental policy is exogenous. Thus, we abstract from optimal policy design in the current setting and conduct standard comparative dynamic exercises with respect to a change in policy (both the regulatory and non-regulatory components). This implies that we interpret policy uncertainty as the result of asymmetric information between the government and the public (e.g. Rodrik, 1989).[4]

The paper continues as follows: In Section II the stylized economy is described and the concept of policy uncertainty is introduced. In Section III the approximate symmetry between political rhetoric and regulation in policy design is demonstrated. Section IV discusses the long run properties of the model. In Section V the path-dependence properties of model and its political economy implications are discussed. Section VI contains a brief discussion of the behavior of the model under a simple learning rule. The conclusion is presented in Section VII.

[4] Another possibility is that the government's behavior is dynamically inconsistent (e.g. Kydland and Prescott, 1977; Fischer, 1980). But this would require modeling the government's objective, which is beyond the scope of this paper. Also, the results in the current discussion are, to some degree, more general.

## II. The Stylized Economy

2.A. *Households*

Consider the following stylized economy populated by a continuum of Barro (1974) style dynastic households, $L(t)$, that grow at the exponential rate, $n$. For simplicity, normalize initial household size to unity. As in Aghion and Howitt (1992), the model employs three different types of labor to maintain Constant Returns to Scale (CRS) across the sectors of the economy that assume price-taking behavior. In particular, each household member is endowed with three types of labor that are inelastically supplied to the labor market: First, there is a unit of intellectual labor, $L_I(t)$, which the individual allocates between research and development, earning a wage rate $w_{RI}(t)$, and final goods production, earning a wage rate $w_{FI}(t)$. Second, there is a unit of entrepreneurial labor, $L_E(t)$, which is also supplied to the R&D sector earning a wage rate $w_E(t)$. Third, there is a unit of physical labor, $L_P(t)$, which is supplied to the final goods sector for abatement needs, earning a wage rate $w_P(t)$. Each household member also saves for the future, $s(t)$, which earns a return of $R(t)$.

Combining the wage earnings from each type of labor with the individual's saving decision provides us with a standard per capita budget constraint.

(1) $$\dot{s}(t) = (R(t) - n)s(t) + w(t) + Tr(t) - c(t)$$

(2) $$w(t) = w_{FI}(t)l_{FI}(t) + w_{RI}(t)l_{RI}(t) + w_E(t) + w_P(t)$$

The variable $w(t)$ defines total labor income, $l_{FI}(t) = L_{FI}(t)/L(t)$ is the fraction of intellectual labor allocated to the final goods sector, and $l_{RI}(t) = L_{RI}(t)/L(t)$ is the fraction of intellectual labor allocated to the R&D sector. Finally, $Tr(t)$ measures government transfers to the household and $\dot{s}(t) = ds/st$.

Household welfare is a linear function of consumption $c(t)$ and an *unknown* additive aggregate flow pollution function, $u[P(t)]$, which is external to the household's decision problem.[5]

(3) $$W(0) = \int_0^\infty e^{-(r-n)t}\left[c(t) + u(P(t))\right]dt .$$

The household discounts future consumption and the environment at the rate $(r-n)$, which is strictly positive to ensure welfare is bounded. The linear utility assumption implies that the solution to the household's optimal control problem, the maximization of equation (3) subject to equations (1) and (2) along with the standard transversality condition, results in an interest rate that equals the rate of time preference, $R(t) = r$ for $\forall t$, along the optimal consumption path (Aghion and Howitt, 1992). We will use this property when we discuss the capital stock and consumption dynamics of the economy.

The exact properties of the damage function are by assumption unobservable, although, we do assume that $\partial u/\partial P < 0$ for $P(t) \geq 0$ and $u(0) = 0$. This set of assumptions implies that pollution reduces utility, but since we do not know the exact properties of the damage function optimal policy design is not feasible. Therefore, a potential government intervention is to introduce a pollution or emissions 'target' to be reached at some time in the future.

2.B. *Production*

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[5] We denote per capita variables with small case letters and aggregate variables with upper case letters.

Production occurs in three sectors: a final goods sector, an abatement goods sector, and an R&D sector.

2.B.1. *Final Goods Production*

The representative firm in the final goods sector operates in a competitive market and employs a Cobb-Douglas production function that combines physical capital $K(t)$ and intellectual labor $L_{FI}(t)$ to produce the final good. The capital share is $\alpha \in (0,1)$ and the general productivity parameter is $B > 1$. The representative firm may also have to pay a tax $\tau(t)$ for each unit of pollution generated by the production process. Physical capital does not depreciate. The representative firm, therefore, maximizes the following (aggregate) profit function:

(4) $$\Pi_F(t) = BK(t)^{\alpha} L_{FI}(t)^{1-\alpha} - rK(t) - w_{FI}(t)L_{FI}(t) - AC(t) - \tau(t)P(t).$$

The variable $AC(t)$ equals the total cost of abatement, and the variable $\tau(t)P(t)$ equals the total pollution tax paid by the firm to the government.

Aggregate pollution is a positive linear function of the capital stock. The firm can also take steps to reduce emissions by using abatement services currently available. This results in the following pollution or ecological equation:

(5) $$P(t) = \sigma K(t) - vL_P(t)^{1-\gamma} \int_0^{A(t)} X(j,t)^{\gamma}\, dj\ .$$

The parameter $\sigma > 0$ determines the intensity of pollution per unit of capital and the parameter $v > 0$ determines the overall productivity of the abatement process. The variable $X(j,t)$ is the amount of abatement good $j \in [0, A(t)]$ employed by the firm at time $t$. The parameter $\gamma \in (0,1)$ measures the curvature of a particular abatement technology. Also, by construction, each of the abatement goods is a flow variable or service. This reduces the dimensionality of the problem with little loss of content (e.g. Barro and Sala-I-Martin, 1995). Finally, assume that each of the abatement goods sells for the price $P(j,t)$, resulting in the following abatement costs,

$$(6) \qquad AC(t) = \int_0^{A(t)} P(j,t)X(j,t)dj + w_P(t)L_P(t).$$

The solution to the (final goods) firm's problem results in the following optimal decision rules.

$$(7) \quad l_{FI}(t) = \left[\frac{(1-\alpha)B}{w_{FI}(t)}\right]^{\frac{1}{\alpha}} k(t) \qquad (8) \quad k(t) = \left[\frac{\alpha B}{r + \tau(t)\sigma}\right]^{\frac{1}{1-\alpha}} l_{FI}(t) = g(\tau)l_{FI}(t)$$

$$(9) \quad x(j,t) = \left[\frac{\tau(t)\gamma v}{P(j,t)}\right]^{\frac{1}{1-\gamma}} \qquad (10) \quad w_P(t) = \tau(t)v(1-\gamma)\int_0^{A(t)} x(j,t)^{\gamma} dj$$

Equation (7) determines the firm's demand for intellectual labor as a fraction of the population. Equation (8) determines the per capita demand for capital, $k(t) = K(t)/L(t)$. The function $g(\tau)$ defines the parametric term for later reference, where $\partial g/\partial\tau < 0$. Finally, the last two optimality conditions, equations (9) and (10), determine the per capita demand for each abatement good available at time $t$, $x(j,t) = X(j,t)/L(t)$, and the payment to physical labor in the abatement process, $w_P(t)$, respectively. Also note that $L_P(t) = L(t)$ by definition, which ensures that the final goods sector satisfies the CRS property necessary for price taking behavior.

2.B.2. *Production of the Abatement Goods*

Abatement goods are produced using a simple linear technology that converts one unit of the final good into one unit of a particular abatement good. A single firm with monopoly rights produces each of the abatement goods in a market of monopolistic competition. Under these assumptions, abatement producer $j \in [0, A(t)]$ maximizes the following aggregate profit function:

(11) $$\Pi_A(j,t) = (P(j,t) - 1)X(j,t).$$

Using equation (9) (in the aggregate), and optimizing over the price, $P(j,t)$, yields the standard markup condition, $P(j,t) = \gamma^{-1}$, for all abatement goods in all time periods. Substituting the optimal price back into equations (9) and (11) results in a set of symmetric per capita demand functions and profit functions for $j \in [0, A(t)]$, respectively:

(12) $$x(j,t) = X(j,t)/L(t) = (\tau(t) v \gamma^2)^{\frac{1}{1-\gamma}} = x(\tau),$$

(13) $$\pi_A(j,t) = \Pi_A(j,t)/L(t) = (\gamma^{-1} - 1)x(\tau) = \pi_A(\tau).$$

The key properties of equations (12) and (13) are summarized by the following Lemma.[6]

<u>Lemma 1</u>: *A decrease in the pollution tax $\tau(t)$ decreases the demand for each abatement good, $\partial x/\partial \tau > 0$, and decreases the profits of each abatement firm, $\partial \pi_A/\partial \tau > 0$.*

2.B.3. *Research and Development*

As in Romer (1990), each abatement producer must purchase a patent from the R&D sector of the economy before actual production can take place. The production of each abatement technology or blueprint combines intellectual labor $L_{RI}(t)$ and entrepreneurial labor $L_E(t)$ in the following manner.

(14) $$\dot{A}(t) = \delta L_{RI}(t)^{\psi} L_E(t)^{1-\psi}$$

[6] The proofs are provided in the appendix. Also, symmetric interpretations apply throughout the paper.

The parameter $\psi \in (0,1)$ determines the intellectual labor share and $\delta > 0$ is an overall efficiency parameter.

2.B.4. *Rhetoric and the Expected Value of the Patent*

Since the government's willingness or ability to implement and enforce current environmental regulations in the future may change as political regimes or parties change power, or as economic circumstances change, the return to R&D investment by the private sector is uncertain. To capture this effect, we represent the government's environmental position with respect to the current set of regulations, or in our case the pollution tax, with the rhetoric parameter $\varepsilon_g \in (-D, D)$. For analytical purposes, we then describe society's perception of the government's environmental position with a Poisson process governed by the function $\lambda(\varepsilon_g)$. This expectations function maps the government's environmental position into a well-defined probability distribution over future regulatory design. To be more specific, society believes that the government will continue to enforce the pollution tax with probability $\exp\{-\lambda(\varepsilon_g)(s-t)\}$ within the time interval $[t,s]$, where $s \geq t$. Thus, society believes that the government will discontinue the current pollution tax with probability $1-\exp\{-\lambda(\varepsilon_g)(s-t)\}$ within the same time interval $[t,s]$. Although this specification is highly stylized it is sufficient for our purpose, which is to demonstrate the potentially important relationship between policy uncertainty, political rhetoric, and environmental policy design.[7]

[7] The cumulative distribution function for the discontinuation of the pollution tax within the interval $[t,s]$ is $F(s \mid t) = 1-\exp\{-\lambda(\varepsilon_g)(s-t)\}$ and the probability density function is the exponential distribution $f(x) = \lambda(\varepsilon_g)^{-1} \exp\{-\lambda(\varepsilon_g)x\}$, which is the continuous time analog of a Poisson process.

We also make the following parametric assumptions about the expectations function. First, the function $\lambda(\varepsilon_g)$ is continuous with respect to the parameter $\varepsilon_g$ over the appropriate interval. Second, we associate a value of zero for the rhetoric parameter, $\varepsilon_g = 0$, when an environmental position is consistent with the current pollution tax. This implies that we can interpret the parameter $\varepsilon_g \in (-\mathrm{D}, \mathrm{D})$ as the relative distance between the *announced* environmental position and the current regulation. Also, rhetoric consistent with the current regulation, $\varepsilon_g = 0$, takes on a positive level of general uncertainty, $\lambda(0) = \overline{\lambda} > 0$. Finally, and the key assumption of the paper, is that an increase in $\varepsilon_g$ increases the probability society assigns to the discontinuation of the current set of regulations, $\partial\lambda/\partial\varepsilon_g > 0$. In other words, as $\varepsilon_g$ increases, the probability society assigns to the continuation of the pollution tax over the time interval $[t, s]$ decreases, as can be seen in the probability assignment $\exp\{-\lambda(\varepsilon_g)(s-t)\}$.

What motivates this relationship between the expectations function $\lambda(\varepsilon_g)$ and the environmental positioning parameter $\varepsilon_g$? Conceptually we can think of a government that announces a policy position in greater opposition to the current set of regulations is also more willing to invest the political capital to try to overturn the current regulation. Society understands this relationship, which implies that $\partial\lambda/\partial\varepsilon_g > 0$.

For closure, we assume that as $\varepsilon_g$ approaches $D$, $\lambda(\varepsilon_g)$ approaches infinity, and $\exp\{-\lambda(\varepsilon_g)(s-t)\}$ approaches zero. A symmetric argument can be made for the opposite case where the government announces an environmental position below zero, $\varepsilon_g \in (-D, 0)$, which implies $\lambda(\varepsilon_g) \in (0, \overline{\lambda})$.

Combining the government's announced environmental position, or rhetoric, the expectations function $\lambda(\varepsilon_g)$, and the pollution tax, provides us with the following definition.

Definition: *A government's environmental policy in the presence of policy uncertainty is described by the pair $(\tau, \varepsilon_g)$, which is composed of a regulatory component of policy, the pollution tax $\tau(t)$, and a non-regulatory component of policy, the government's announced environmental position relative to the current regulation, $\varepsilon_g$.*

We now use this definition, along with the fact that households are risk-neutral, to define the expected R&D profit function and the expected value of the patent.

$$(15) \qquad E_t[\Pi_R(t)] = E_t[V(t)]\delta L_{RI}(t)^{\psi} L_E(t)^{1-\psi} - w_{RI}(t)L_{RI}(t) - w_E(t)L_E(t).$$

$$(16) \qquad E_t[V(t)] = \int_t^{\infty} e^{-(r+\lambda(\varepsilon_g))(s-t)}\Pi_A[\tau(s)]ds = V^E(\tau, \varepsilon_g).$$

Equation (16) shows that the expected value of the patent equals the expected present value of the profits generated by the production and sale of the abatement good. The additional profit stream under the discontinuation of the policy, weighted by $1-\exp\{-\lambda(\varepsilon_g)(s-t)\}$, does not appear in equation (16) because $\pi_A(\tau)=0$ when $\tau=0$ (see equations (12) and (13)).

Assuming that the current regulation imposes a constant pollution tax on firms, $\tau(s-t)=\tau$ for all $s \geq t$, an assumption made throughout the remainder of the paper,[8]

[8] This assumption does not imply that policy cannot change, only that the current regulation imposes the same tax rate on future pollution.

and after substituting aggregate profits for each abatement firm defined in equation (13), $\Pi_A[\tau] = L(s)\pi_A(\tau)$, into equation (16), then integrating with respect to time provides us with the following lemma for $V^E(\tau, \varepsilon_g)$.

<u>Lemma 2</u>: (i) *A decrease in the pollution tax* $\tau$ *decreases the value of the patent,* $\partial V^E / \partial \tau > 0$. (ii) *An increase in the government's announced opposition to the current pollution tax, an increase in* $\varepsilon_g$ *, also reduces the value of the patent,* $\partial V^E / \partial \varepsilon_g < 0$.

This lemma demonstrates that a decrease in the pollution tax reduces the value of a patent by decreasing the demand for abatement goods. This lemma also demonstrates that an increase in the government's announced opposition to current regulation reduces the value of the patent because abatement firms now assign a higher probability to the discontinuation, or non-enforcement, of the pollution tax in the future.[9]

Finally, substitute equation (16) into (15) to derive the demand schedule for intellectual labor as a fraction of the labor force, $l_{RI}(t)$, and the payment to entrepreneurial labor, respectively:

$$(17) \quad l_{RI}(t) = \left[ \frac{V^E(\tau, \varepsilon_g)\partial\psi}{w_{RI}(t)} \right]^{\frac{1}{1-\psi}} \qquad (18) \quad w_E(t) = V^E(\tau, \varepsilon_g)(1-\psi)\delta l_{RI}(t)^{\psi}.$$

2.C. *Closing the Model*

To close the model, assume the government operates a balanced budget and transfers all revenue back to the households in a lump-sum fashion.

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[9] It is important to recognize that the decline in the value of a patent is not the direct result of a change in the degree of uncertainty. In fact, as $\lambda(\varepsilon_g)$ increases, the variance of the future profit stream decreases.

$$(19) \qquad Tr(t) = \tau p(t) = \tau\left(\sigma k(t) - vA(t)x(\tau)^{\gamma}\right)$$

The variable $p(t) = P(t)/L(t)$ equals the per capita level of pollution. Also assume that the labor market operates efficiently. This implies the following equilibrium condition and full-employment condition for intellectual labor.

$$(20) \quad w_{RI}(t) = w_{FI}(t) \qquad\qquad (21) \quad l_{RI}(t) + l_{FI}(t) = 1$$

The last step is to define household consumption. Here, we assume that payments to labor in the R&D sector take the form of equity ownership of the abatement firms. Since there is free-entry into the R&D sector, equity ownership will exhaust each R&D firm's profits, which results in the following factor payment from the abatement sector at time $t$: $l_R(t)w_{RI}(t) + w_E(t) = L(t)^{-1}\int_0^{A(t)} \Pi_A(j,t)dj = A(t)\pi_A(\tau)$. This equation, along with equations (7), (10), (18), and (2), provides us with total wage income:

$$(22) \qquad w(t) = \underbrace{(1-\alpha)Bk(t)^{\alpha} l_{FI}(t)^{1-\alpha}}_{w_{FI}(t)l_{FI}} + \underbrace{A(t)\pi_A(\tau)}_{l_R(t)w_{RI}(t)+w_E(t)} + \underbrace{\tau v(1-\gamma)A(t)x(\tau)^{\gamma}}_{w_P(t)}.$$

Now we find per capita consumption by combining equations (1), (8), (12), (13), (19), and (22), along with the assumption that the capital market clears, $s(t) = k(t)$.

$$(23) \qquad c(t) = Bk(t)^{\alpha} l_{FI}(t)^{1-\alpha} - nk(t) - A(t)x(\tau).$$

That is, consumption equals production minus replacement capital minus the cost of producing each of the abatement goods available at time $t$, all in per capita terms. Also note that $\dot{k}(t) = 0$ for $\forall t$ because the rate of return to capital investment must equal $r$ for $\forall t$, the rate of time preference. In effect, the linear utility assumption instantaneously places the final goods production side of the economy on its balanced growth path. This property allows us to isolate the transitional properties of the abatement sector and its implications for the other sectors of the economy.

## III. The Comparative Dynamics of Regulation and Rhetoric

This section of the paper uses a series of comparative dynamic exercises to demonstrate the approximate equivalence between a change in the regulatory component of policy and a change in the non-regulatory component of policy. In particular, it is shown that the government can weaken an environmental policy by either decreasing the pollution tax or by announcing an environmental position in opposition to the tax. Symmetric arguments also apply.

3.A. *The Equilibrium Allocation of Intellectual Labor*

We begin our analysis in the labor market. After solving the subsystem of equations (7), (8), (17), (20), and (21), we have the following equilibrium employment shares for intellectual labor:

$$(24)\quad l_{RI}(t)=\left[\frac{V^{E}(\tau,\varepsilon_g)\delta\psi}{(1-\alpha)Bg(\tau)^{\alpha}}\right]^{\frac{1}{1-\psi}}=l_{RI}(\tau,\varepsilon_g)\qquad (25)\quad l_{FI}(\tau,\varepsilon_g)=1-l_{RI}(\tau,\varepsilon_g).$$

Next, using equations (14) and (24), and assuming $A(0)=0$, we derive the time path for the development of new abatement technologies as a function of the government's environmental policy:

$$(26)\qquad A(t)=L(t)\left[1-e^{-nt}\right]\frac{\delta l_{RI}(\tau,\varepsilon_g)^{\psi}}{n}.$$

Equations (24), (25), and (26) provide us with the following proposition:

Proposition 1: *Given an environmental policy* $(\tau, \varepsilon_g)$, *there exists a unique and stationary allocation of intellectual labor between final goods production and the development of new abatement technologies in the per capita economy. This results in a unique abatement technology development path* $A(t)$.

We summarize the properties of this proposition in **Figure 1**. The upper panel shows the labor market clearing condition for intellectual labor using equations (7) and (17). Here we see that there is a unique solution associated with the fraction of intellectual labor employed in the R&D sector, as described by equation (24). Given this unique solution, the bottom panel of figure 1 demonstrates that there is a unique level of abatement technology development at every point in time for this allocation. This translates into the unique abatement development path described by equation (26).

The following comparative dynamics follow from the above system of equations.

Proposition 2: *Given the environmental policy* $(\tau, \varepsilon_g)$: (i) *A decrease in the pollution tax decreases employment in the R&D sector,* $\partial l_{RI} / \partial \tau > 0$, *increases employment in the final goods sector,* $\partial l_{FI} / \partial \tau < 0$, *and decreases the entire abatement development path,* $\partial A(t) / \partial \tau > 0$. (ii) *An increase in the government's announced opposition to the pollution tax also reduces employment in the R&D sector,* $\partial l_{RI} / \partial \varepsilon_g < 0$, *increases employment in the final goods sector,* $\partial l_{FI} / \partial \varepsilon_g > 0$, *and decreases the entire abatement development path,* $\partial A(t) / \partial \varepsilon_g < 0$.

Proposition 2 demonstrates that a decrease in the pollution tax decreases employment in the R&D sector for a given environmental position. This result is shown in the upper panel of **Figure 2**. The lower panel of figure 2 shows that the decrease in R&D employment reduces abatement technology development at every point in time, which shifts the entire abatement development path down. Proposition 2 also demonstrates that a similar result holds after an increase in the government's announced opposition to the current pollution tax, an increase in $\varepsilon_g$. The opposition to the pollution tax reduces the expected value of a patent, which reduces employment in the R&D sector and the development of new abatement technologies. This result is also represented by **Figure 2**.

3.B. *The Dynamics of Pollution and Consumption*

Before discussing the relationship between the government's environmental policy and the time path of pollution and consumption consider the following lemma:

Lemma 3: *Given the pair* $(\tau, \varepsilon_g)$ *there exists a stationary per capita capital stock* $k(\tau, \varepsilon_g) = g(\tau) l_{FI}(\tau, \varepsilon_g)$ *with the following properties:* (i) *A decrease in the pollution tax increases the demand for capital,* $\partial k / \partial \tau < 0$. (ii) *An increase in the government's rhetorical opposition to the pollution tax also increases the demand for capital,* $\partial k / \partial \varepsilon_g > 0$.

There are two reasons a decrease in the pollution tax increases the demand for capital. First, a lower pollution tax decreases the user cost of capital. Second, the lower pollution tax increases the fraction of intellectual labor employed in the final goods sector. This increases the demand for capital because labor and capital are complements. This complementarities condition also explains why an increase in the government's opposition to the pollution tax moves physical capital in the same direction. An increase in the rhetoric in opposition to the current regulation increases employment in the final goods sector, which in turn increases the demand for capital.

We now use lemma 3, along with equation (5) and the results of proposition 2, to describe the following aggregate pollution dynamics:

<u>Proposition 3</u>: *Given the pair* $(\tau, \varepsilon_g)$ *and the following equation for pollution,* $P(t) = L(t)\left(\sigma k(\tau, \varepsilon_g) - vA(t)x(\tau)^{\gamma}\right)$*:* (i) *A decrease in the pollution tax increases the time path of pollution,* $\partial P(t)/\partial \tau < 0$. (ii) *An increase in the government's rhetorical opposition to the pollution tax also increases the time path of pollution,* $\partial P(t)/\partial \varepsilon_g > 0$.

The first part of proposition 3 demonstrates that a lower pollution tax increases the entire time path of pollution. This is because the lower pollution tax decreases the use of the existing abatement technologies and decreases the rate of development of new abatement technologies. The second part of proposition 3 demonstrates that the government's rhetorical opposition to the pollution tax will also result in a higher pollution path because there are less abatement technologies available at any given point in time.

The last piece of the dynamic puzzle is consumption, equation (23).[10]

[10] If $r - n < \tau\sigma$ then the consumption results are analytically ambiguous, although all the other results carry over. Here we are assuming the economy is dynamically efficient, $r - \sigma\tau = F_K > n$.

Proposition 4: *Assume* $r-n\geq\sigma\tau$. *Given the pair* $(\tau,\varepsilon_g)$ *and consumption profile* $c(t)=Bk(\tau,\varepsilon_g)^{\alpha}l_{FI}(\tau,\varepsilon_g)^{1-\alpha}-nk(\tau,\varepsilon_g)-A(t)x(\tau)$: (i) *A decrease in the pollution tax increases consumption,* $\partial c(t)/\partial\tau<0$. (ii) *An increase in the government's rhetorical opposition to the pollution tax also increases consumption,* $\partial c(t)/\partial\varepsilon_g>0$.

Proposition 4 formally demonstrates that a lower pollution tax and an increase in the government's rhetorical opposition to the pollution tax both increase the time path of consumption.

**IV. Sustainability**

We now address the issue of sustainability and long run balanced growth in our stylized economy.

Proposition 5: *Assume the government implements a transition pollution tax* $\tau^T$ *for a given announced environmental position* $\varepsilon_g\in(-D,D)$ *and initial condition* $A(0)=0$. *Also assume this transition tax is chosen so that the economy reaches a zero pollution level in finite time* $T$ *with* $A(T)$ *abatement technologies such that,*

$$(a)\quad P(T)=L(T)\underbrace{\left(\sigma k(\tau^*,N)-A(T)x(\tau^*)\gamma\right)}_{zero}=0\qquad (b)\quad A(T)=L(T)\left[1-e^{-nT}\right]\frac{\delta l_{RI}(\tau^T,\varepsilon_g)^{\psi}}{n},$$

*where a balanced growth tax* $\tau^*$ *maintains these conditions for* $t\geq T$. *Finally assume the government does not issue any new abatement patents for* $t\geq T$. *This implies that there exists a balanced growth path satisfying the following conditions*:

*(c)* $l_{FI}(\tau^*, N) = 1$ *and* $l_{RI}(\tau^*, N) = 0$ *(d)* $\frac{\dot{K}(t)}{K(t)} = \frac{X(\dot{j},t)}{X(j,t)} = \frac{\dot{C}(t)}{C(t)} = \frac{\dot{L}(t)}{L(t)} = n$; $\dot{P}(t) = 0$.

*The term* $N$ *implies 'non-applicable' because patents are no longer being issued. An economy satisfying conditions (a)-(d) is said to be in an environmental-economic equilibrium as of date* $T$ *and the transition path is described by the environmental policy*$(\tau^T, \varepsilon_g)$ *for* $t \in [0, T)$.

This proposition demonstrates that our stylized economy can sustain a zero level of pollution within finite time $T$ in the aggregate.[11] The logic of the balanced growth path is rather straightforward. As the capital stock grows with the population, $\dot{K}(t)/K(t) = n$, which tends to increase pollution, the *use* of existing abatement technologies $A(T)$ also grows with the population, $X(\dot{j},t)/X(j,t) = n$, which offsets the additional pollution generated by a larger aggregate capital stock (equation (d) in the proposition). If $n = 0$, that is there is no population growth, the aggregate economy is stationary. Thus, in our setting, only abatement technology development is endogenous.

The reason the government may want to announce an emissions target for some time in the future, $T$, is because the actual damage to household utility is unknown, by assumption, in our stylized model. This implies that optimal policy design is not feasible. The government may compromise with different factions in society by implementing a regulation that allows the economy to gradually reduce the pollution level over time. The

[11] We could easily conceive of the pollution level being in terms of deviations form some positive level $\overline{P}$.

Kyoto Protocol is an obvious example, although, there are numerous other examples of these types of policies.

It is important to note that political rhetoric matters in a world with policy uncertainty in this stylized dynamic setting because the regulatory component of the environmental policy is not sufficient to pin down a unique economic and environmental transition path. The current model eliminates this indeterminacy by specifying an expectations-function that maps the government's environmental position into a well-defined distribution that describes society's beliefs about the future. In effect, the government 'steers' or guides expectations through its use of political rhetoric by 'picking' the transitional dynamic trajectory of the economy and the environment.

**V. Political Economy Implications of Environmental Policy**

In section III we demonstrated, through a sequence of propositions, that the regulatory and rhetorical components of an environmental policy can have roughly the same effect on the dynamic properties of the economy and the environment. These results suggest that a government lacking the political capital or will to actually change an environmental regulation can accomplish this task, at least in part, through the use of political rhetoric. For the particular case presented above, it was shown that the government could weaken an environmental regulation by announcing its opposition to the current regulation, the pollution tax. It was also argued that as the degree of *rhetorical* opposition towards the pollution tax increased, the effects on the economy and the environment were more pronounced.

To conceptualize this argument, consider the following example. First, assume the government in power wants to reduce the pollution tax but does not have the political capital to accomplish this task. Also, assume that this lack of political capital is private information held by the government. Second, assume that the government announces a policy $\varepsilon_g > 0$ in opposition to the current pollution tax $\tau$. Finally, without loss of generality, assume that the initial policy position was consistent with the current regulation, $\varepsilon_g = 0$. This results in two environmental policy regimes: one where the government supports the pollution tax, $\varepsilon_g^1 = 0$, and the other where the government opposes the pollution tax, $\varepsilon_g^2 > 0$. In the second regime there is less intellectual labor employed in the R&D sector. This implies that fewer abatement goods are developed at every point in time relative to the first regime, as shown in the upper panel of **Figure 3**. Thus, the second regime lies strictly below the first regime because firms assign a higher probability to the discontinuation of the pollution tax.

The political-economy implication of this result is that the government can systematically alter the time path of pollution and consumption through rhetoric, in this case more consumption and more pollution as shown in the lower panels of Figure 3, by changing society's expectations. As an extreme case the government can temporarily undo the reallocation part of regulation by stating that their objective is to completely dismantle the current regulation. In our theoretical framework as $\varepsilon_g \to D$ and $\lambda(\varepsilon_g) \to \infty$, society no longer allocates any resources to the R&D sector. This argument is similar to Glazer (1990), Cukierman and Meltzer (1986) and Shepsle (1972), although in a different context, who demonstrate that a position of political ambiguity can increase the probability of re-election in a partisan economy where the political party's constituency matters. Here political rhetoric, or ambiguity about the future of the environmental regulation, changes the dynamic behavior of the economy and the environment.

Parts (a) and (b) of proposition (5) also describe the relationship between the government's environmental position and the cost of achieving an environmental target in finite time $T$, which we define as $\overline{A}(T)$ in figure 3. To formally demonstrate the relative importance of this aspect of environmental policy design, first define the transition tax in terms of the balanced growth tax $\tau^T = \tau^A + \tau^*$, where $\tau^A$ is the tax differential. Second, from part (a) we have the zero pollution condition $\sigma k(\tau^*, N) = A(T)x(\tau^*)\gamma$ and from part (b) we have the abatement technologies available at time $T$. Equating these two conditions provides us with the following policy function:

$$(27) \qquad \left(e^{nT} - 1\right)\frac{\delta l_{RI}\left(\tau^A + \tau^*, \varepsilon_g\right)^{\psi}}{n} = \frac{\sigma k\left(\tau^*, N\right)}{\gamma x\left(\tau^*\right)}.$$

This equation describes the relationship between the policy variables, $T$ through $A(T)$, the balanced growth tax $\tau^*$, the transition tax differential $\tau^A$, and the government's environmental position $\varepsilon_g$. Obviously all these policy variables are related through this single equation. But, since the objective here is to determine the relationship between the transition tax and the government's environmental position, not optimal policy design, we assume that the government's time frame for reaching $A(T)$ is given, therefore $\tau^*$ is given.

After totally differentiating equation (27) with respect to the transition policy $\left(\tau^A, \varepsilon_g\right)$ we have the following relationship:

$$(28) \qquad \frac{\partial \tau^A}{\partial \varepsilon_g} = -\frac{\partial l_{RI} / \partial \varepsilon_g}{\partial l_{RI} / \partial \tau^A} > 0.$$

This result demonstrates that the pollution tax during the transition must increase at some time in the future if the government's announced opposition to the current pollution tax increases and the long-term objective of reaching the zero pollution 'target' by time $T$ remains. This implies that it will be more costly to implement a long-term environmental policy, or reach the environmental target, if the government uses political rhetoric to achieve short-term consumption gains. Thus, future administrations or generations must incur a higher cost in terms of consumption loss to achieve the environmental objective or the objective itself must be postponed or abandoned.

This stylized model also suggests that empirical studies attempting to estimate the effects of environmental regulation on induced innovation, pollution, and consumption must also control for the political side of environmental policy design. Failure to do so will lead to omitted variable bias and provide an inconsistent and possibly incorrect assessment of the overall effect of the regulation. Once again, consider the example where the government weakens environmental policy using the non-regulatory component of policy design, that is, political rhetoric. Specifically, assume there is a regulation, $\tau$, that has a positive correlation with induced innovation and negative correlation with pollution or emissions, that is, $\text{cov}(\tau, I) > 0$ and $\text{cov}(\tau, P) < 0$, where $I$ denotes new abatement technologies or innovation. Now assume a new government or administration announces a policy position in opposition to the current regulation, $\varepsilon_g > 0$. This announcement has a negative correlation with induced innovation and a positive correlation with pollution, that is, $\text{cov}(\varepsilon_g, I) < 0$ and $\text{cov}(\varepsilon_g, P) > 0$. This is in direct opposition to the effectiveness of the regulation itself. This implies that a statistical assessment of the relationship between the environmental regulation and the affect on the variables of interest, induced innovation and pollution, will be biased towards zero if we do not account for the government's non-regulatory component of policy design and society's expectations about future policy. In effect, we falsely conclude that the regulation was ineffective based on the statistical evidence, but in fact it is the non-regulatory component that is responsible for the statistical relationship, or lack thereof, between the regulation and variables of interest when the non-regulatory component is incorrectly omitted from the analysis.

**VI. Learning about False Policy Announcements**

The presentation in the previous sections implicitly assumed that a government's policy position is perceived as permanent within the dynamics of the economy and the environment. This simplification is mainly for expositional reasons and to highlight the relationship between policy uncertainty, political rhetoric, and the dynamic properties of the economy and the environment. This assumption can easily be relaxed so that society learns about *false* policy announcements.

Consider the following stylized learning rule given an initial environmental policy announcement $\varepsilon_g(0) \in (-D, D)$.

$$(29) \qquad \dot{\varepsilon}_g(t) = -\omega \varepsilon_g(t) \text{ or } \varepsilon_g(t) = e^{-\omega t}\varepsilon_g(0) \text{ for } t \geq 0$$

The parameter $\omega > 0$ represents the rate at which society learns that policy announcements are false. From this simple learning rule it follows that any initial policy announcement, $\varepsilon_g(0)$, will dissipate back towards the status quo policy position, $\varepsilon_g = 0$. Also, it should be clear that all of the previous results carry over to the case with learning with the modification that the future effects are dampened. In terms of the example presented in figure 3, the approximate dynamic paths are between the two cases. In particular, the larger the learning parameter (the faster the learning process) the closer the trajectories are to the case where $\varepsilon_g^1 = 0$, and the smaller the learning parameter (the slower the learning process) the closer the trajectories are to the case where $\varepsilon_g^2 > 0$. Given the long implementation lags between policy announcements and the actual implementation of policy, or a change in policy, in democratic societies with complex regulatory processes it is likely the latter case (relatively slow learning) which holds.

**VII. Conclusion**

This paper examines the role of government rhetoric and the design of environmental policy in a world with policy uncertainty. It shows that governments have the ability to systematically influence the investment and abatement decisions of firms by altering their expectations about future environmental regulation. Within this context, it also shows that the use of rhetoric in opposition to the current set of regulations have roughly the same effect on the dynamic behavior of the economy and the environment as a change in the regulation itself.

There is one general political-economy theme that emerges from our analysis. In a world with policy uncertainty, a government that wants to change a current environmental regulation but lacks the political power, or will, to actually accomplish this task can use political rhetoric and gestures instead. That is, the government can signal to firms that their intention is to change or alter the current regulation (whether the government intends to follow through with the policy announcement or not) rather than going through the actual regulatory design process.

## Appendix

Proofs for the Lemmas:

Lemma 1: Proof: Follows directly from equation (12) and (13). ■

Lemma 2: Assume that $t = 0$, which implies that $L(t) = L(0) = 1$ given our normalization. From lemma (1) we know that $\frac{\partial \pi_A}{\partial \tau} > 0$, therefore, $\frac{\partial V^E}{\partial \tau} = \left(\frac{1}{r - n + \lambda(\varepsilon_g)}\right)\frac{\partial \pi_A}{\partial \tau} > 0$. Also, since $\frac{\partial \lambda}{\partial \varepsilon_g} > 0$, this implies $\frac{\partial V^E}{\partial \varepsilon_g} = -\left(\frac{\pi_A(\tau)}{(r - n + \lambda(\varepsilon_g))^2}\right)\frac{\partial \lambda}{\partial \varepsilon_g} < 0$. ■

Lemma 3: Stationarity follows directly from equations (8), (24), and (25), and proposition (1). The first part of lemma (3) follows from lemma (1), proposition (2), and the following derivation, $\frac{\partial k}{\partial \tau} = l_{FI}(\tau, \varepsilon_g)\frac{\partial g}{\partial \tau} + g(\tau)\frac{\partial l_{FI}}{\partial \tau} < 0$. The second part of lemma (3) also follows from proposition 2 and the derivation $\frac{\partial k}{\partial \varepsilon_g} = g(\tau)\frac{\partial l_{FI}}{\partial \varepsilon_g} > 0$. ■

Proofs for the Propositions:

Proposition 1: Stationarity follows directly from equations (24) and (25) under the assumption that $\tau$ and $\varepsilon_g$ are constant. (Path) Uniqueness follows directly from equation (14) given $l_{RI}(\tau, \varepsilon_g)$ is constant. Note that by construction, $L_E(t) = L(t)$. ■

Proposition 2: (i) Using equation (24) and lemmas (1) and (2) we have the following,

$$\frac{\partial l_{RI}}{\partial \tau} = \left[\frac{V^E(\tau, \varepsilon_g)\delta\psi}{(1-\alpha)Bg(\tau)^\alpha}\right]^{\frac{\psi}{1-\psi}}\left(\frac{1}{1-\psi}\right)\left(\frac{\delta\psi}{(1-\alpha)Bg(\tau)^\alpha}\frac{\partial V^E}{\partial \tau} - \frac{V^E(\tau, \varepsilon_g)\delta\psi\alpha}{(1-\alpha)Bg(\tau)^{1+\alpha}}\frac{\partial g}{\partial \tau}\right) > 0.$$

From equation (25), we have the result $\frac{\partial l_{FI}}{\partial \tau} = -\frac{\partial l_{RI}}{\partial \tau} < 0$. From equation (27) we have the result $\frac{\partial A(t)}{\partial \tau} = L(t)\left[1 - e^{-nt}\right]\frac{\varepsilon\psi\delta l_{RI}(\tau, \varepsilon_g)^{\psi-1}}{n}\frac{\partial l_{RI}}{\partial \tau} > 0$. (ii) We approach part two in a similar fashion, $\frac{\partial l_{RI}}{\partial \varepsilon_g} = \left[\frac{V^E(\tau, \varepsilon_g)\delta\psi}{(1-\alpha)Bg(\tau)^\alpha}\right]^{\frac{\psi}{1-\psi}}\left(\frac{1}{1-\psi}\right)\left(\frac{\delta\psi}{(1-\alpha)Bg(\tau)^\alpha}\frac{\partial V^E}{\partial \varepsilon_g}\right) < 0$, which implies that $\frac{\partial l_{FI}}{\partial \varepsilon_g} = -\frac{\partial l_{RI}}{\partial \varepsilon_g} > 0$ and $\frac{\partial A(t)}{\partial \varepsilon_g} = L(t)\left[1 - e^{-nt}\right]\frac{\varepsilon\psi\delta l_{RI}(\tau, \varepsilon_g)^{\psi-1}}{n}\frac{\partial l_{RI}}{\partial \varepsilon_g} < 0$. ■

Proposition 3: (i) From Lemma (3) and proposition (2) we have the following result with respect to the pollution path, $\frac{\partial P(t)}{\partial \tau} = L(t)\left[\sigma \frac{\partial k}{\partial \tau} - vx(\tau)^{\gamma} \frac{\partial A(t)}{\partial \tau} - \gamma v A(t) x(\tau)^{\gamma-1} \frac{\partial x}{\partial \tau}\right] < 0$. (ii) Also from Lemma (3) and proposition (2) we have, $\frac{\partial P(t)}{\partial \varepsilon_g} = L(t)\left[\sigma \frac{\partial k}{\partial \varepsilon_g} - vx(\tau)^{\gamma} \frac{\partial A(t)}{\partial \varepsilon_g}\right] > 0$. ■

Proposition 4: (i) From lemma (3) and propositions (2) and (3) we have the following,

$$\frac{\partial c(t)}{\partial \tau} = \left[(r - n - \sigma\tau)\frac{\partial k}{\partial \tau} + (1-\alpha)Bk(\tau, \varepsilon_g)^{\alpha} l_{FI}(\tau, \varepsilon_g)^{-\alpha} \frac{\partial l_{FI}}{\partial \tau} - x(\tau)\frac{\partial A(t)}{\partial \tau} - A(t)\frac{\partial x}{\partial \tau}\right] < 0,$$

where the substitution of $r - \tau\sigma$ for $\alpha Bk(\tau, \varepsilon_g)^{\alpha-1} l_{FI}(\tau, \varepsilon_g)^{1-\alpha}$ comes from equation (8). (ii) Also from lemma (3) and propositions (2) and (3) we can conclude that the following,

$$\frac{\partial c(t)}{\partial \varepsilon_g} = \left[(r - n - \sigma\tau)\frac{\partial k}{\partial \varepsilon_g} + (1-\alpha)Bk(\tau, \varepsilon_g)^{\alpha} l_{FI}(\tau, \varepsilon_g)^{-\alpha} \frac{\partial l_{FI}}{\partial \varepsilon_g} - x(\tau)\frac{\partial A(t)}{\partial \varepsilon_g}\right] > 0. \text{ ■}$$

Proposition 5: Condition (a) follows from the dynamic properties of the abatement technology described in equation (26), culminating in condition (b). Condition (c) holds as a result of the fact that no new patents are issued for $t > T$. Also policy uncertainty is no longer an issue for the same reason, $A(T)$ is sunk cost for the abatement firms. Part (d) follows from equation (8), $K(t) = \left[\frac{\alpha B}{r + \tau^{*}\sigma}\right]^{\frac{1}{1-\alpha}} L(t)$, which implies the aggregate capital stock grows at the rate $n$. A similar argument applies to the use of each abatement technology, $X(j,t) = x(\tau^{*})L(t)$. The household's aggregate consumption profile, $C(t) = \left(Bk(\tau, \varepsilon_g)^{\alpha} - nk(\tau^{*}, N) - A(T)x(\tau^{*})\right)L(t)$ for $t > T$, implies that this also grows at the rate as the population. Thus, the economy lies on a balanced growth path with no pollution for $t > T$. ■

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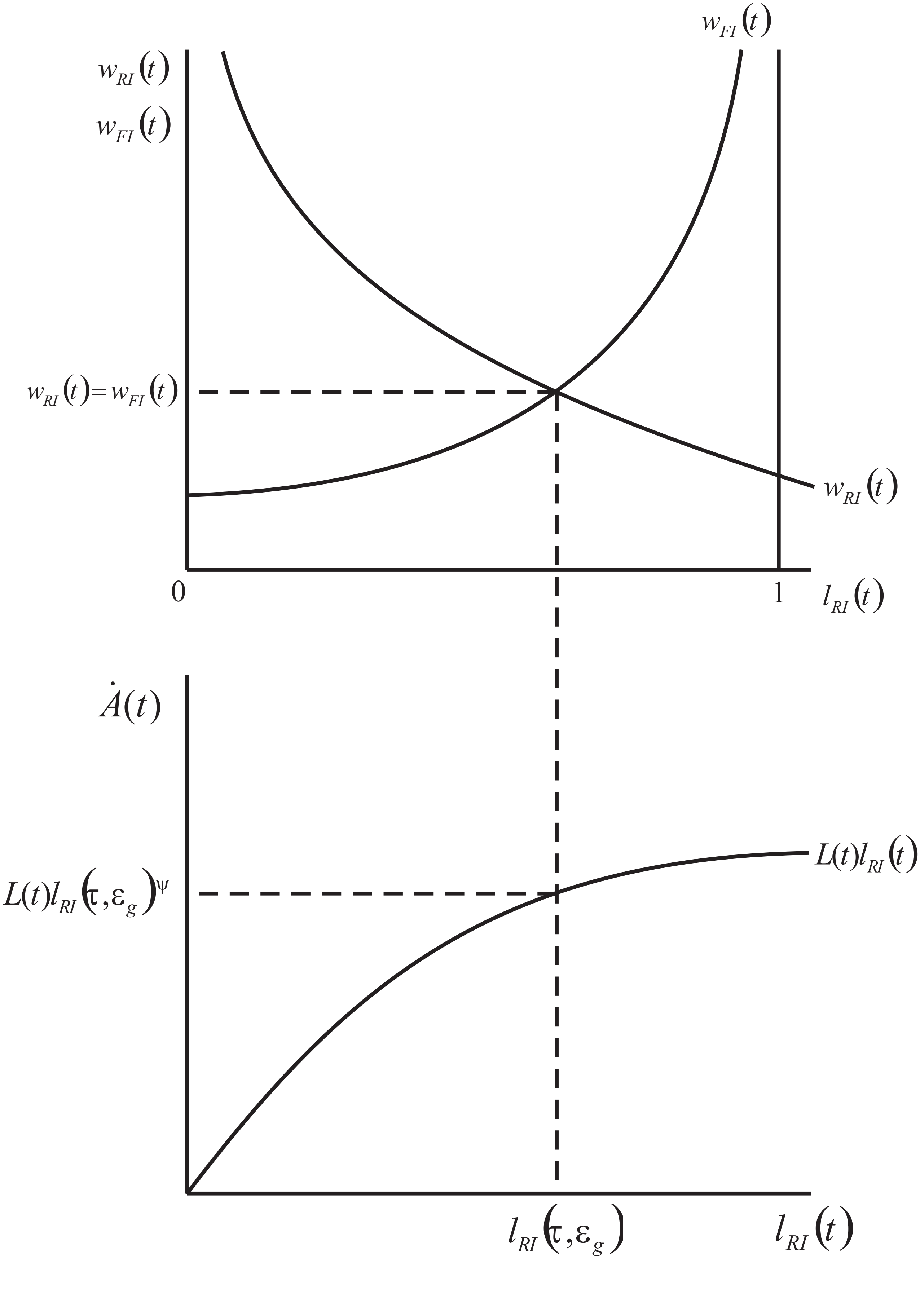


Figure 1: Intellectual Labor Market Equilibrium and the Abatement Technology Development Path

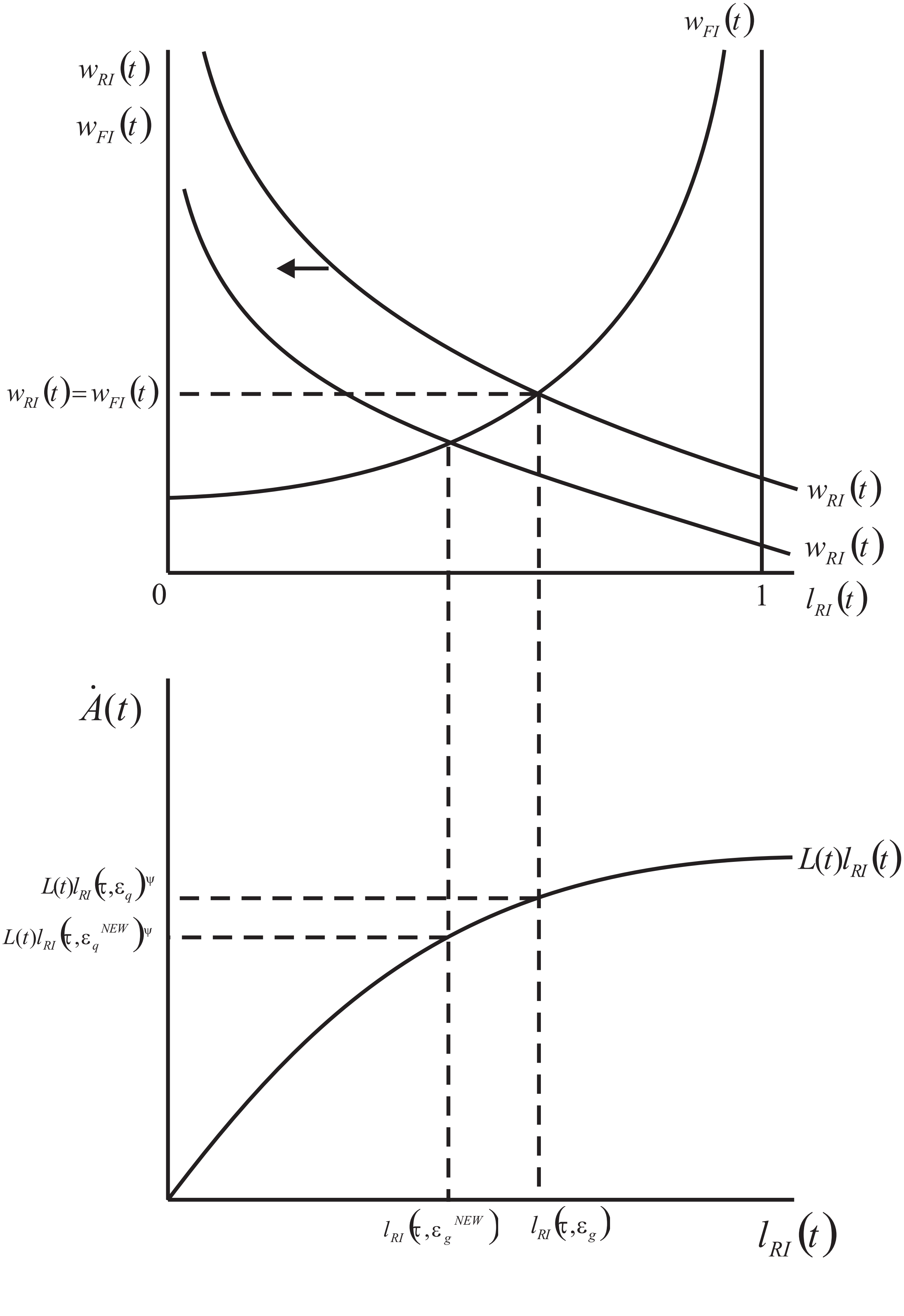


Figure 2: Decrease in Abatement Technology Development from a Decrease in Regulation or Governmental Position in Opposition to Current Regulation

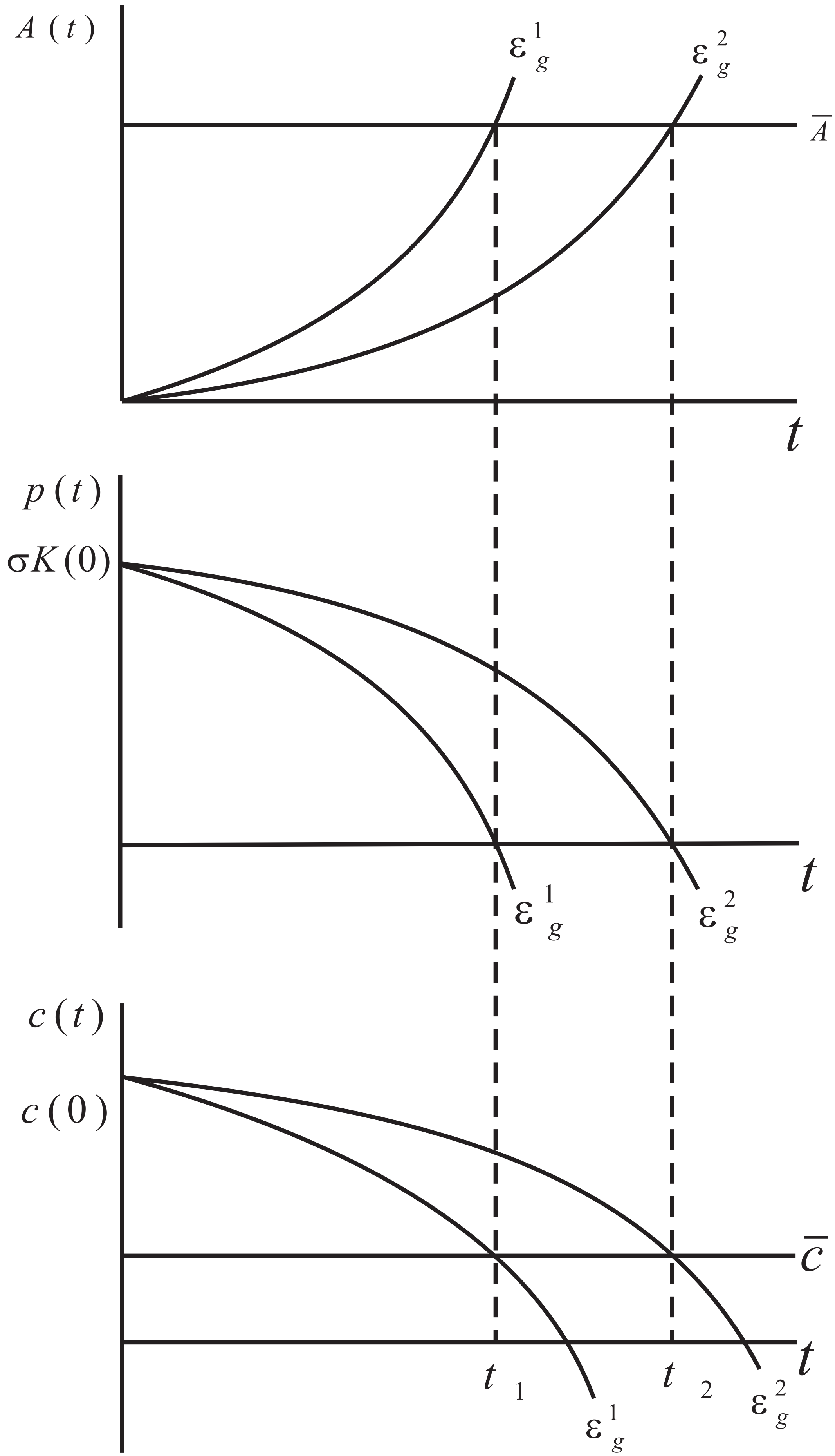


Figure 3: Political Economy Implications of Rhetoric