# Optimal commitment under uncertainty: adjustment rules for climate policy

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**Abstract**

Under uncertainty, climate policy faces a fundamental trade-off between commitment and flexibility. While commitment to future policy reduces the risk of time inconsistency and investment hold-up, it imposes costs in the form of reduced flexibility to respond to unforeseen developments. This paper analyses the interaction between regulator and firms when climate damages are uncertain. In a sequential game, the regulator announces an abatement target and firms respond by choosing their level of technology. Finally, the regulator - who faces costs if deviating from its announcement - sets the actual policy. Our main conclusions emphasize that if the regulator commits to a specific abatement level in advance, less than perfect commitment is desirable and the expected level of welfare falls short of the first-best outcome. If, however, the regulator can commit to an adjustment rule that sets the abatement level contingent on the realization of the uncertain outcome or can employ technology subsidies that cover the full costs of firms' technology choice, the social optimum can be obtained.

Keywords: climate policy, uncertainty, time inconsistency, commitment, adjustment rule

JEL classifications: D81, H23, H32, O31

# 1 Introduction

Taking effective action to avoid dangerous climate change requires credible commitment to long-term climate policy (Helm et al. 2003, Brunner et al. 2011). A problem, however, arises if the policy is prone to the risk of time inconsistency. The general concept of time inconsistency – elaborated in the context of macroeconomic policy by Kydland and Prescott (1977) – describes a situation in a dynamic game in which the regulator's best plan for some future time period is no longer optimal when that point in time actually arrives, i.e. the regulator has an *ex-post* incentive to renege on a policy that was optimal *ex-ante* (Petit, 2009). In the context of climate policy, it has been recognized that the development and adoption of innovative low-carbon technologies by the private sector may be impeded by time-inconsistency: in order to provide incentives for firms to undertake irreversible investments in R&D, the regulator has to announce a high future carbon price. Once these investments are undertaken, however, the socially optimal *ex post* carbon price set by the regulator is too low for firms to recoup their investment (Kennedy and Laplante, 2000; Requate and Unold, 2003; Montgomery and Smith, 2005). As firms anticipate this outcome, the regulator's announcement is not credible and under-investment results.

Several devices to deal with the problem of time-inconsistency in carbon pricing have been proposed. All of them increase the regulator's cost of changing policy *ex post* and thus allow to 'tie its hands' to some extent. Section 4 provides a discussion of different commitment devices, which, according to Brunner et al. (2011) can be grouped into three categories: legislation, delegation, and securitization. First, legislation includes the formulation of policy adjustment rules conditional on pre-defined parameter changes that are beyond the influence of regulated entities (Rodrik and Zeckhauser, 1988). Second, part of the authority to set climate policy can be delegated to independent institutions that have a time horizon beyond the current legislative period and stronger incentives to build up and retain reputation for sticking to *ex ante* policy commitments over longer time horizons (Helm et al., 2004), akin to the task of a central bank in monetary policy. Third, securitization serves to entrench commitments in private property rights and contracts, as for instance issuing financial options on emission allowances (Laffont and Tirole, 1996; Ismer and Neuhoff, 2009). Furthermore, it has been pointed out that subsidies can induce the socially desirable level of R&D because they avoid the intertemporal incentive problem pertaining carbon pricing (Abrego and Perroni, 2002; Ulph and Ulph, 2009; Golombek et al., 2010).

While commitment devices offer ways to enhance the credibility of policies, regulators also wish to retain flexibility in order to be able to react to unforeseen developments, such as abrupt technological innovation or new scientific evidence regarding the impacts of climate change (Abrego and Perroni, 2002). As has been pointed out by Rogoff (1986) for the case of monetary policy, it is optimal to appoint a central banker who places a large, but finite, weight on inflation. Surprisingly, the literature on credible long-term environmental policy has remained predominantly silent with regard to this trade-off between commitment and flexibility. Lyon (1991) investigates under which conditions hindsight review (in which a utility is punished for bad outcomes of a risky investment) can be superior to *ex-ante* rate of return regulation. Blackmon and Zeckhauser (1992) examine a regulatory game with uncertainty and show that delegating regulation of utilities (e.g. power generators) to an entity whose preferences are biased in favor of firms' interests also serves consumers' interests by inducing higher investment levels. Boyer and Laffont (1999) show that constraining the choice of instruments available to politicians can limit their undue promotion of the interests of their constituency. However, equipping politicians with discretionary power is the more desirable the greater the variability of relevant economic parameters such as firms' costs, stakeholders' preferences, or the social costs of public funds.

The approach presented in this article illustrates the commitment-flexibility trade-off in a sequential three-stage game between firms and a regulator in which the benefits of climate policy are uncertain. Through some commitment device, the costs of deviating from the policy announced in the first stage of the game enter the regulator's objective function, such that a trade-off emerges: lower punishment for deviation increases the flexibility to accommodate new information, but lowers the ability to credibly commit.

This article contributes to the literature as follows: first, it provides an intuition why regulators announce future policies even if they might have *ex-post* incentives to deviate, and illustrates how an announcement may influence its later actions as well as firms' expectations. Second, it shows that in presence of uncertainty, neither perfect nor total absence of commitment but some intermediate level achieves the optimal outcome. Third, it demonstrates that if the resolution of uncertainty can be observed *ex-post*, the first-best outcome can be obtained with a state-contingent rule that determines the amount of emissions abatement to be provided as a function of the uncertain variable. Finally, we show that if lump-sum subsidies are feasible, the regulator can also achieve the first-best outcome by subsidizing firms to choose the socially optimal level of technology.

This paper proceeds as follows: Section 2 presents a generalized Stackelberg game in which the social optimum is obtained if the regulator can commit to a certain policy but time inconsistency emerges if firms move first. We then introduce a term into the regulator's objective function that punishes deviations from announced policies. This generalizes the polar cases of full commitment and no commitment and is well-suited to describe intermediate cases. Section 3 derives the optimal level of commitment under uncertainty and shows that the social optimum can be achieved with a credible commitment to an adjustment rule. Section 4 discusses commitment devices and implementation options. Section 5 concludes.

# 2 A general formulation of time inconsistency and commitment

One example for time inconsistency is the case in which a regulator announces a future climate policy *ex ante,* but has an incentive to adapt policy if the regulated entities set their policies in anticipation of the regulator's incentives for *ex post* policy adjustment. Consider a regulator that decides about the aggregate level emissions abatement $e$ (the climate policy) to be provided by firms that can lower their costs by investing in technology $t$ at R&D cost $\vartheta(t)$. With $b(e)$ and $c(e,t)$ denoting the (social) benefits and (firms') costs of *e*, respectively, the first-best solution is obtained maximizing the following social welfare function:

$$W = b(e) - c(e,t) - \vartheta(t) \tag{1}$$

Calculating the derivatives yields the following first-order conditions for the optimal values of *e* and *t*[1]:

(i) $b_e(e^{opt}) = c_e(e^{opt}, t^{opt})$, and (2)

(ii) $c_t(e^{opt}, t^{opt}) + \vartheta_t(t^{opt}) = 0$ (3)

Let us consider a three stage game à la Stackelberg. First, the regulator announces a policy. Second, firms invest to emission saving technologies. In the final stage of the game, the regulator implements a policy (carbon tax, emission trading system, or standards) to achieve the socially optimal level of abatement *e*. This formulation captures essential properties of long-term climate policy.

*Lemma 1: If the regulator has a device to credibly commit to e, the socially optimal outcome can be obtained.*

Proof: In the decentralized solution, firms choose their level of technology *t* to minimize their total costs $c(e,t) + \theta(t)$. If the regulator is able to credibly commit to its choice of *e*, it opts for $e^{opt}$ in the second stage, firms choose technology $t^{opt}$, and the socially optimal outcome is obtained. □

*Lemma 2: If the regulator is unable to credibly commit to the announced level of* e*, the firms choose technology level* t *which is below the social optimum as compared to the case with credible commitment. The same holds for the regulator's choice of* e.

[1] Subscripts denote partial derivatives

Proof: If the commitment is not credible, firms anticipate the government's reaction when deciding about their level of technology. In this case, the regulator's first-order condition in the final and decisive period, taking the firms choice of technology as given, becomes:

$$b_e(e^{reg}) = c_e(e^{reg}, t^f)\,. \tag{4}$$

This condition implicitly defines the regulator's reaction function to firms' choice of technology. It can easily be verified that $\frac{de^{reg}}{dt^{firms}} > 0$, i.e. the regulator responds to firms' choice of a lower level of technology by adopting a less ambitious emissions abatement target. The firms' technology choice is determined by their cost minimization problem, taking into account the regulator's reaction function:

$$\min_t [c(e,t) + \vartheta(t)] \Rightarrow$$

$$c_e(e^{reg}, t^f)\frac{de^{reg}}{dt^f} + c_t(e^{reg}, t^f) + \vartheta_t(t^f) = 0 \tag{5}$$

As the first term is positive, $c_t(e^{reg}, t^f) + \vartheta_t(t^f) < 0$, this means that the social cost of supplying *e* is not at a minimum, as would be required by the optimality condition $c_t(e,t) + \vartheta_t(t) = 0$, but could be further decreased by increasing *t*. However, given the regulator's reaction function, such an increase in *t* would also raise the total level of emissions abatement *e* that firms are required to provide. □

Anticipating that technological innovations that lower their marginal cost schedule prompt the regulator to adopt more stringent policy, firms choose a level of technology below the social optimum. This 'ratchet effect' (Weitzman, 1980) is the source of time inconsistency in our model[2]. However, this problem can be overcome if the regulator has

[2] Note that by modeling one representative firm, we implicitly assume that firms are able to coordinate their actions. If a single firm's action has no influence on the regulator's reaction, the problem of time-inconsistency does not arise in our framework. Thus the time consistency formulation chosen here can be

a means to credibly commit to its future actions. It is well known that a commitment is only credible if the cost of breaking it exceeds the potential gains from deviation (Schelling, 1960). That is, the regulator does only have an incentive to adhere to a prior commitment if deviating results in a punishment that is sufficiently large such that it is not worthwhile. If the punishment depends on the magnitude of the deviation from the announced policy, the regulator's optimal *ex-post* policy is determined by its *ex-ante* commitment and the severity of the punishment for deviating. In this formulation, if the punishment for an infinitesimally small deviation from the announced policy approaches infinity, the regulator never has an incentive to deviate from the announced policy and perfect commitment is obtained.

<u>Lemma 3</u>: *The cases of 'perfect commitment' and 'no commitment' as well as all intermediate cases can be modeled by introducing a punishment function* $\Theta$ *into the regulator's objective function.*

<u>Proof</u>: Let the regulator's objective function be

$$W = b(e) - c(e,t) - \vartheta(t) - \Theta(e - e^{opt}) \text{ with } \Theta' > 0 . \qquad (6)$$

Obviously, the case of no commitment is obtained for $\Theta(e) = 0$. Furthermore, it can be easily verified that $\frac{de^{reg}}{dt^{firms}} \to 0$ for $\Theta(e \neq e^{opt}) \to \infty$, which yields the full commitment setup. Between these polar cases lies a continuum of setups in which the regulator is punished for deviations from the pre-announced policy. □

With perfect foresight, it is clear that perfect regulatory commitment is the most desirable option from a social perspective. However, in presence of uncertainties with regard to benefits and costs of emissions abatement, some flexibility to deviate from prior announcements in order to react to unforeseen events can prove advantageous. Therefore,

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expected to be suitable for monopolistic and oligopolistic markets, such as power generation in many countries.

as we show in the next section, there is a trade-off between adopting strong commitment devices to strengthen the time-consistency of a policy versus the flexibility to accommodate new information.

## 3 Commitment under uncertainty

We outline a simple analytical model with linear benefits, quadratic abatement costs decreasing linearly in investment in technology *t*, and a quadratic R&D investment cost function to acquire technology level *k*. We analyze the impacts of additive uncertainty in the slope of the benefit function[3], assuming that the magnitude of the regulator's punishment $\Theta$ for deviating from an announced target is characterized by parameter $\theta$ and quadratic in the difference between the announcement $e^*$ and the actually implemented level $e'$. This formulation of a commitment device can be understood in terms of the reputational costs associated to violating a pledge à la Barro and Gordon (1983), or political costs in terms of renegotiating legislation (Brunner et al., 2011). Monetary costs can be introduced in an emission trading system by means of put options that obligate the regulator to buy back permits at a pre-defined price in the future (Ismer and Neuhoff, 2009). Section 4 discusses such devices to establish credible commitment in more detail.

The model is hence fully specified by the following set of equations:

$$\begin{aligned} b(e) &= (b+\varepsilon)e';\ E(\varepsilon)=0;\ Var(\varepsilon)=\sigma^2 \\ c(e) &= \frac{1}{2}ce'^2 - te' \\ \vartheta(t) &= \frac{1}{2}kt^2 \\ \Theta(e',e^*) &= \frac{1}{2}\theta(e'-e^*)^2 \end{aligned} \tag{7}$$

[3] In climate policy, the largest source of uncertainty remains with regard to the benefits of avoiding the most serious impacts of climate change, see e.g. IPCC (2007), Lenton et al. (2008), and Smith et al. (2009). At the same time, uncertainties regarding mitigation costs and costs of technology development undeniably play important roles, too.

We require all parameters $b$, $c$, $k$ and $\theta$ as well as the choice variable $t$ to be non-negative. The social welfare function is given by:

$$W = (b + \varepsilon)e' - \frac{1}{2}ce'^2 + te' - \frac{1}{2}kt^2 - \frac{1}{2}\theta(e' - e^*)^2 \tag{8}$$

Again, the game proceeds in three stages: In the first stage, the regulator (R) announces the target $e^*$ which it aims to implement in the final stage. In the second stage, the uncertainty regarding benefits is resolved and firms (F) choose their level of technology $t$.[4] In the third stage, the regulator decides on the level of emissions abatement that is actually implemented ($e'$), given the realization of the new information $\varepsilon$ regarding benefits as well as firms' choice of $t$, and firms supply $e'$ at the corresponding cost function (Figure 1).

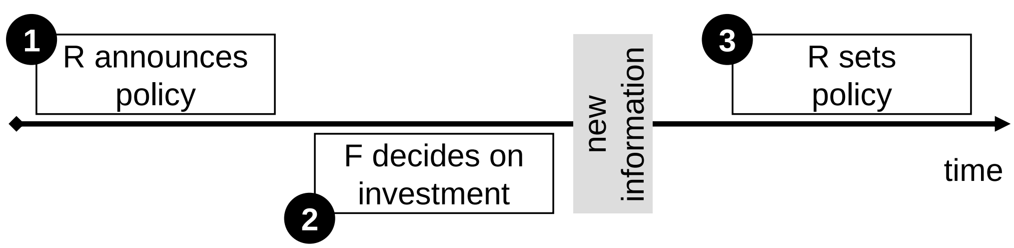


**Figure 1: Emissions game between regulator (R) and firm (F) under uncertainty**

The decentralized nature of the strategic interaction between the regulator and the regulated firms requires both players to form expectations of future scenarios (which are determined by the other player's action, and, for the regulator, the possible realization of the shock). To solve the problem, we apply backward induction from the third to the second and finally to the first stage.

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[4] Hence, firms do not face uncertainty when deciding on their technology level

*The Third Stage*

In the third stage, the regulator chooses $e^{'}$, the level of emissions abatement to be performed by the firms, taking as given technology *t*, the realization of the shock $\varepsilon$, as well as $e^{*}$ (its own announcement of the first stage). Its maximization problem then yields:

$$e' = \arg\max_{e'}[W] = \arg\max_{e'}\left[(b+\varepsilon)e' - \frac{1}{2}ce'^2 + te' - \frac{1}{2}kt^2 - \frac{1}{2}\theta(e^{'} - e^{*})^2\right] \Rightarrow$$

$$e' = \frac{(b+\varepsilon) + t + \theta e^{*}}{c+\theta} \tag{9}$$

The level of emissions abatement that the regulator actually requires firms to supply is the higher (i) the larger actual benefits, i.e. $(b+\varepsilon)$, (ii) the higher the firms' level of technology *t*, (iii) the more ambitious the announced target $e^{*}$, and (iv) the lower marginal abatement costs *c*.

*The Second Stage*

In the second stage, firms take the regulator's announced policy $e^{*}$ as given from the first stage and anticipate how it will react in the third stage to their second stage choice of *t*. Firms observe the shock $\varepsilon$ occurring to the benefit function and decide which level of technology to employ in order minimize their total costs:

$$t' = \arg\min_{t} \frac{1}{2}ce^{'}(\varepsilon, t, e^{*})^2 - te^{'}(\varepsilon, t, e^{*}) + \frac{1}{2}kt^2 \tag{10}$$

As firms are able to solve the regulators decision problem in the third stage, inserting $e'$ in Eq.(10) results in the following solution for the firms' technology choice *t'*:

$$t^{'} = \frac{\theta(b+\varepsilon) + \theta^2 e^{*}}{k(c+\theta)^2 - c - 2\theta} \tag{11}$$

For an inner solution (i.e. cost minimum) to exist, let us assume that the condition $k > \frac{c+2\theta}{(c+\theta)^2}$ holds. Then, $t'$ increases with (i) actual benefits $(b+\varepsilon)$, (ii) the regulator's announced policy $e^*$, and (iii) the strength of the regulator's commitment to its announced target ($\theta$), as all parameters cause firms to anticipate that stricter requirements will be put into place by the regulator in stage three.

*The First Stage*

In order to be able to decide which target $e^*$ to announce before knowing the actual realization of $\varepsilon$, the regulator has to form expectations about social welfare under all possible outcomes. Plugging the expressions for $e'$ and $t'$ into the welfare function and rearranging terms results in:

$$W = \frac{[\theta e^* + b + \varepsilon]^2[(k(c+\theta)-1)^2 - k\theta^2] - \theta[k(c+\theta)^2 - c - 2\theta]^2 e^{*2}}{2[k(c+\theta)^2 - c - 2\theta]^2} \tag{12}$$

Taking expectations then yields:

$$W^e = \frac{[\theta^2 e^{*2} + b^2 + 2b\theta e^* + \sigma^2][(k(c+\theta)-1)^2 (c+\theta) - k\theta^2] - \theta[k(c+\theta)^2 - c - 2\theta]^2 e^{*2}}{2[k(c+\theta)^2 - c - 2\theta]^2} \tag{13}$$

Maximizing this expression with respect to $e^*$ then gives us the regulator's optimal choice of $e^*$, which is only a function of parameters:

$$e^* = \frac{b[(k(c+\theta)-1)^2(c+\theta) - k\theta^2]}{[k(c+\theta)^2 - c - 2\theta]^2 - \theta[(k(c+\theta)-1)^2(c+\theta) - k\theta^2]} \tag{14}$$

*Welfare*

Inserting $e^*$ into the expression for expected welfare and rearranging terms yields:

$$W^e = \frac{b^2[(k(c+\theta)-1)^2(c+\theta)-k\theta^2]}{2[k(c+\theta)^2-c-2\theta]^2-2\theta[(k(c+\theta)-1)^2(c+\theta)-k\theta^2]} + \frac{\sigma^2[(k(c+\theta)-1)^2(c+\theta)-k\theta^2]}{2[k(c+\theta)^2-c-2\theta]^2} \tag{15}$$

*Proposition 1: With uncertainty and committing to a pre-announced policy $e^*$, neither the case of full nor the case of no commitment yields the optimal result. Rather, an intermediate value of $\theta$ (i.e. $0 < \theta < \infty$) provides a socially optimal mix of commitment and flexibility.*

Proof: Calculating the derivative of expected welfare with respect to $\theta$ and evaluating the expression at the extreme values $\theta = 0$ and $\theta \to \infty$ shows that $\left.\frac{\partial W^e}{\partial \theta}\right|_{\theta=0} > 0$ and $\left.\frac{\partial W^e}{\partial \theta}\right|_{\theta\to\infty} < 0$. □

Therefore, for the design of a commitment device, a social planner deciding on the regulator's responsibilities would choose the value of $\theta$ such that it maximizes expected welfare. It is not possible to derive an analytical expression for the maximum of the above expression for expected welfare. However, one can employ numerical methods[5] to calculate the values of $\theta$ that maximize $W^e$ for different sets of parameters. The result of this exercise is shown in Figure 2, which plots the optimal value of $\theta$ as a function of $b^2/\sigma^2$. This set of graphs[6] suggests that the optimal level of commitment (i) increases as expected benefits $b$ increase and uncertainty $\sigma$ decreases, and (ii) decreases with higher marginal abatement costs $c$ as well as technology costs $k$. This finding is in line with intuition: the optimal level of commitment is the higher the higher the benefits of mitigation relative to costs, and the lower uncertainty over benefits.

[5] We used Matlab's bounded minimization routine fminbnd

[6] Please note that the optimal $\theta$ is always strictly larger than zero

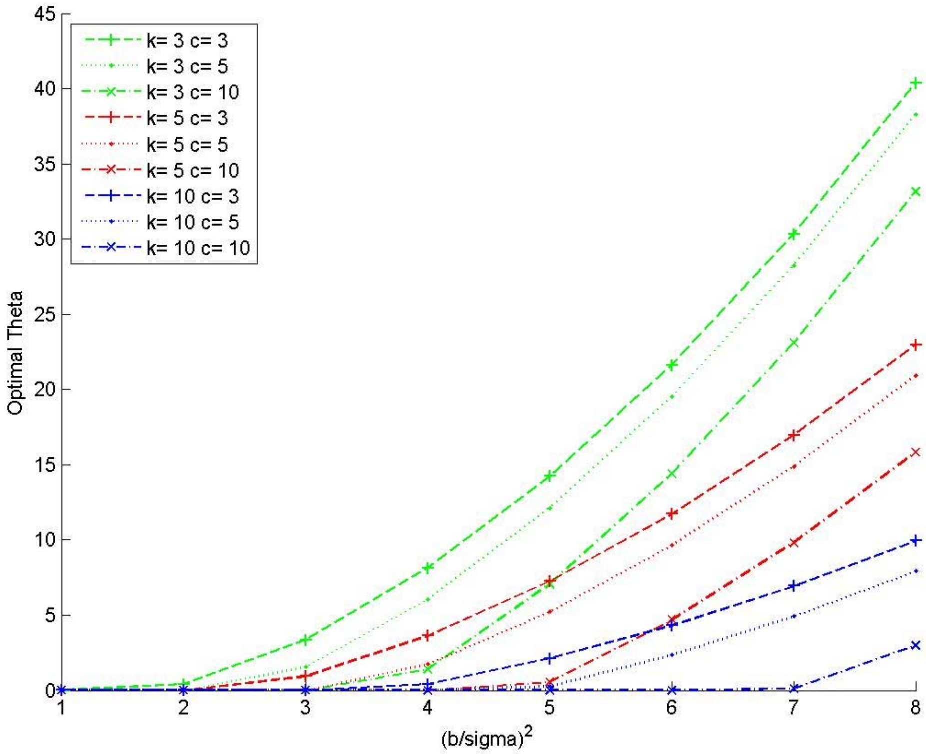


**Figure 2: Optimal level of commitment for different values of the parameters *k* and *c***

*First best solution*

Like in the example presented in Section 2, the first best outcome could be obtained by simultaneously choosing *e* and *t* after observing the realization of $\varepsilon$, such that the first-order conditions $b_e(e^{opt}) = c_e(e^{opt}, t^{opt})$ and $c_t(e^{opt}, t^{opt}) + \vartheta_t(t^{opt}) = 0$ are fulfilled. This would result in the following policy:

$$\begin{aligned} t^{opt} &= \frac{b+\varepsilon}{kc-1} \\ e^{opt} &= \frac{k(b+\varepsilon)}{kc-1} \end{aligned} \tag{16}$$

Plugging these expressions in the social welfare function and taking expectations yields:

$$W^{e,opt} = \frac{(b^2 + \sigma^2)}{2(kc-1)} \qquad (17)$$

<u>Proposition 2</u>: *With uncertainty, the expected welfare of committing to a pre-announced policy* $e^*$ *is strictly inferior to the social optimum, regardless of the level of commitment* $\theta$.

<u>Proof</u>: Comparing expressions for welfare in the commitment under uncertainty case (Eq.(15)) and the socially optimal case (Eq.(17)) reveals that the two expressions differ, i.e. . $W^e \neq W^{e,opt}$. As the social optimum of Eq.(17) corresponds to the optimal choice of *e'* and *t* (which maximizes expected welfare), Eq.(15) has to lie strictly below and hence can not be a social optimum. □

*Commitment to an adjustment rule*

With uncertainty, there is no a-priori commitment to a specific $e^*$ that yields the first-best outcome. However, instead of commitment to a pre-announced policy, the regulator could aim at committing to a state-dependent policy which is enshrined in an adjustment rule that sets $e^*$ contingent on the realization of ε.

<u>Proposition 3</u>: *The first-best outcome can be achieved if the regulator has the ability to credibly commit to an adjustment rule which implements a certain level of* e *contingent on the realization of the shock* ε.

<u>Proof</u>: As we have shown in Eq.(16), the first-best outcome implies $e^{opt} = \frac{k(b+\varepsilon)}{kc-1}$ and $t^{opt} = \frac{b+\varepsilon}{kc-1}$. By announcing the policy $e^* = \frac{kb}{kc-1}$ and perfectly committing to an adjustment rule that includes a punishment term of the form $\Theta(e^{'} - e^*) = \frac{\theta}{2}(e^{'} - e^* - \frac{k\varepsilon}{kc-1})^2$; $\theta \to \infty$, the regulator can implement the socially optimal level of $e^{'}$ even under uncertainty. This commitment strategy deprives firms of

their incentive to implement a lower level of technology in order to influence the regulator's choice of $e^{'}$. As can easily be verified, their cost-minimization problem results in choosing the socially optimal level of technology $t^{opt}$. □

Hence, perfect commitment to a rule that adjusts the regulator's policy is both time-consistent and optimal. Practical implementation of such policy crucially rests on the assumption that the regulator is able to observe the shocks. This seems intuitive for the case of climate change impacts, which commonly are public knowledge. By contrast, if uncertainty would pertain marginal abatement costs or R&D costs of new technologies - the case not investigated here – significant information asymmetries between firms and government are likely to inhibit adoption of an optimal adjustment rule.

*Technology subsidies*

In our framework, time-inconsistency arises because of the sequential interaction between firms and regulator over time, with the former having an incentive to choose a lower than socially optimal level of technology in order to influence the latter's climate policy decision. Several authors (Abrego and Perroni 2002; Ulph and Ulph 2009; Golombek et al. 2010) have proposed that in this setting the problem of time-inconsistency can be circumvented by subsidizing firms' choice of technology right away. Subsidies change the time structure of regulation by inducing investments as they are being deployed, thus eliminating firms' intertemporal calculus regarding their influence on future policies.

<u>Proposition 4</u>: *If lump-sum subsidies are feasible, the regulator can achieve the first-best outcome by subsidizing the full cost of firms' technology choice. A commitment device is not required.*

<u>Proof</u>: With commitment to a specified level of policy $e^{*}$, firms choose the technology $t^{'} = \dfrac{\theta(b+\varepsilon)+\theta^{2}e^{*}}{k(c+\theta)^{2}-c-2\theta}$, whereas the socially optimal value would be $t^{opt} = \dfrac{b+\varepsilon}{kc-1}$ (cf. Eqs. (11) and (16)). Hence, the regulator can encourage firms to choose the first-best level of technology by offering a subsidy of $t^{opt} - t'$ after observing the realization of $\varepsilon$.

With $t^{opt}$ in place, the level of $e^{'}$ actually chosen by the regulator will be the closer to the first-best level $e^{opt}$ the lower the punishment for deviation, i.e. the lower $\theta$. Specifically, the regulator can always choose $e^{'} = e^{opt}$ if $\theta = 0$. In this case of no commitment, firms choose $t^{'} = 0$ in the second stage, and the subsidy amounts to $t^{opt}$.□

The finding that subsidizing green investment can substitute for a commitment device crucially depends on the assumption that uncertainty is fully resolved at the beginning of the second period. In reality, the situation is more complex, as shocks can be expected to occur frequently. This requires the regulator to include expectations of future shocks when setting the subsidy, and re-adjusting it every time a shock has occurred. In addition, information asymmetries regarding R&D investment functions need to be overcome to ensure an efficient subsidy program. Furthermore, bearing the full costs of firms' technology R&D investment is likely to entail considerable transfers if the required funding is obtained by distortionary taxation.

# 4 Commitment devices

The analytical model introduced a punishment term that incurs costs on the government if it decides to deviate from the committed policy. This punishment term can be implemented by using commitment devices. Kydland and Prescott (1977, p.487) describe them as "institutional arrangements that make it a difficult and time-consuming process to change the policy rules in all but emergency situations". Commitment devices for climate policy help to entrench the abatement target and the adjustment rule in credible structures by introducing costs to policy change (Brunner et al., 2011)[7]. Costs can accrue in various forms: time, bad press, the need to seek cross-partisan consensus, logrolling, losing votes, admonition from courts, financial expenditures etc. Devices that incur such costs do not put an absolute limit on government flexibility. Rather, they provide governments with an incentive to adhere to the announced policy by decreasing the gains

[7] Interestingly, empirical evidence suggests that central banks follow adjustment rules, too, instead of focusing on inflation or interest rate targets (Clarida et al., 2000; Bernanke and Mihov, 1998). See Whitesell (2011) for a discussion of parallels between climate policy and monetary regulation.

from deviation. The key feature is that commitment devices create or support long-term countervailing constituencies interested in emissions abatement. There are three groups of commitment devices: legislation, delegation, and securitization.

First, legislation provides the legal foundation for the abatement target, the adjustment rule and a transparent governance structure for implementing and updating the policy. The legal quality of provisions influences the degree of commitment to a large extent. Commitment by means of constitutional law presents a high hurdle to policy change because constitutional amendments often require qualified majorities. Statutory law typically requires simple majorities. Instead of changing legal provisions, the incumbent could also decide to ignore them. Plausibly, the main motivation for government to avoid non-compliance with law is public scrutiny. If a governing majority anticipates that the political costs of pursuing a certain course of action will be a loss of public support, then taking this route is less attractive. Hence, climate laws should be deliberately designed so as to encourage public scrutiny, for example, by earmarking revenues from emissions trading for redistribution purposes. A large share of the proceeds from auctioning emission permits could be recycled back to consumers via annual lump-sum payouts. By mitigating (for the poorest households potentially reversing) the regressive distributional impact of carbon pricing, a 'climate dividend' payout system could create long-term public support for climate laws.

Second, delegating authority to institutions with a time horizon beyond the current legislative period may help to insulate interests dedicated to emissions abatement from day-to-day politics. The climate law may foresee the establishment of a government independent institution that monitors and advises the government on climate policy. The merit of having an independent watchdog lies in forcing government to publically justify its own actions on a regular basis (Lazarus, 2009). The law may also delegate the authority to set policy on government's behalf to an independent carbon agency (Helm et al., 2003). The advantage is that the new agency can be mandated a reduced set of objectives (emissions abatement) whereas its political principal, the government, pursues multiple and at times conflicting objectives. Multiplicity of objectives is a source of time inconsistency (Tirole, 1994). Furthermore, independent agencies which are insulated from political cycles have stronger incentives to build up and retain reputation over longer time horizons than their political principles (Barro and Gordon, 1983). Using legislation and delegation in combination may therefore allow the government to credibly commit to a future climate policy by (i) legally enshrining abatement target and adjustment rule and (ii) delegating their implementation to an independent carbon agency. The agency retains the flexibility to react to new developments but it does so within the bounds of the adjustment rule.

Third, securitization may be used to protect investors' stakes in carbon markets by entrenching commitment in enforceable contracts. One means to strengthen the commitment to emissions trading systems is to prolong the validity of permits (McKibbin and Wilcoxen, 2007). Long-dated permits allow their owners to emit one unit of emissions each year over the lifespan of the permit (e.g. 30 years). Permit owners have an interest in safeguarding the climate law and in keeping the emissions cap tight because that increases the scarcity value of their asset. They form a countervailing constituency against political attempts by subsequent governments to renege on climate legislation. Alternatively, put-options on emission allowances allow investors to hedge their low-carbon assets against the downside of a carbon price risk while also providing government with a contractual incentive to honor its commitment (Ismer and Neuhoff, 2009). The government, having sold the option, has a financial incentive to keep permit prices above the committed minimum. If the volume of outstanding options is sufficiently large, a price floor for emission allowances will emerge in the carbon market.

There are first attempts to implement adjustment rules and commitment devices in Europe. In the UK, a statutory climate law legislates long-term abatement targets and delegates monitoring duties to a government independent advisory body. Adjustments to abatement targets follow a formal procedure where the advisory body observes developments in the economy, climate science, and international negotiations, and eventually recommends the parliament to adjust abatement targets. Somewhat less transparent adjustment procedures exist at EU level. From 2013 onwards, the emissions cap in the European Union Emissions Trading Scheme (EU ETS) will follow a linear reduction trajectory of -1.74% annually. Directive 2009/29/EC specifies that the reduction factor shall be reviewed and perhaps adjusted after 2020, leaving thereby open for what reasons, in which direction, and to what extent it may change. The formal procedure governing the review process (so-called comitology) has been criticized for its lack of transparency. Moreover, the abatement target may be tightened before 2020 if, amongst others, "*more advanced developing countries*" contribute "*adequately"* to global abatement efforts (Art. 28; Directive 2009/29/EC). Vaguely formulated adjustment rules as these may be necessary to capture the multitude of potential outcomes. But they may also offer loopholes for opportunistic policy change (Dixit, 1996). Hence, there is scope to improve institutional design by making adjustment rules more explicit and governance structures more transparent.

## 5 Conclusions

This paper examines the importance of uncertain climate damages for a regulator's optimal level of commitment to an emissions abatement target. It demonstrates that if the regulator announces an emissions target, intermediate levels of commitment which offer a balance between commitment and flexibility maximize expected welfare. Neither of the polar cases of full commitment and full flexibility is desirable. Numerical simulations confirm the intuition that the optimal level of commitment is the higher the higher the benefits of mitigation relative to its costs, and the lower the uncertainty over benefits.

However, even with the best available *ex ante* commitment to a fixed abatement target, expected welfare falls short of the social optimum. By contrast, the regulator can achieve the first-best outcome by either (a) committing to a state-contingent rule that adjusts the target level depending of the actual realization of the random variable, or (b) fully subsidizing firms' costs of adopting the socially optimal value of technology (assuming that the required funds can be obtained from distortion-free lump-sum taxes). As discussed in the previous section, credible commitment to an adjustment-rule can be established by legislation, delegation, or securitization. However, it should be noted that in practice these commitment devices are subject to limitations such as the difficulty to impartially observe key parameters of the adjustment rule such as climate damages or the outcomes of international negotiations.

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