

Optimal Climate Change Policies When Governments Cannot Commit¹

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Abstract

We analyse the optimal design of climate change policies when a government wants to encourage the private sector to undertake significant immediate investment in developing cleaner technologies, but the relevant carbon taxes (or other environmental policies) that would incentivise such investment by firms will be set in the future. We assume that the current government cannot commit to long-term carbon taxes, and so both it and the private sector face the possibility that the government in power in the future may give different (relative) weight to environmental damage costs. We show that this lack of commitment has a significant asymmetric effect: it *increases* the social benefits of the current government to have the investment undertaken, but *reduces* the private benefit to the private sector to invest. Consequently the current government may need to use additional policy instruments – such as R&D subsidies – to stimulate the required investment.

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1. Introduction

It is widely recognized (e.g. Stern (2007)) that climate change involves two types of externality: reflecting the global nature of the problem there is an intra-temporal externality whereby countries both affect and are affected by the actions of firms and consumers in all other countries; and there is an inter-temporal externality whereby emissions created by one generation cause damage to many future generations. In this paper we focus exclusively on the inter-temporal externality, so in what follows we assume that there is just a single country that both generates and suffers from climate change.

It is also widely recognized (again, see, for example, Stern (2007)) that tackling this inter-temporal externality cannot best be done solely by reducing the consumption and production of “dirty” goods, but will need *large* investments to bring about *radically* new cleaner technologies and products. A conventional economic argument is that if this inter-temporal environmental externality is the only market failure, and if the government of this single country can set a time-path of policy instruments to maximize welfare over an infinite horizon, then the only policy instruments that are needed are environmental policies such as a set of potentially time varying emissions/carbon tax rates⁴. For these emission taxes play a dual function: they induce the optimal levels of output/emissions in every period, and they give firms incentives to undertake investment (including investment in R&D) that will produce cleaner technologies and products. This perspective is consistent with broader discussions of R&D policy outside the

⁴ For example, this is the implication of Proposition 1 in Golombek et al (2010).

environmental context (Jaffe et al (2003)) that innovation incentives are driven by changes in relative prices.

Of course the conclusion that environmental policies alone are sufficient to tackle climate change breaks down once it is recognised that, particularly when we are dealing with R&D, there are other market failures involved - for example appropriability problems or rent-stealing (Jaffe et al (2003)), or imperfect competition (Helm *et al* (2003))⁵. In this paper we assume that either such market failures do not exist⁶, or, equivalently, that governments have sufficient policy instruments to deal with them. We focus instead on a different reason why the simple economic argument may not apply, namely that it assumes that current governments can commit to long-term future tax policies. But in a democratic system current governments may not be able to tie the hands of future governments on emission taxes.

There is now a significant literature on the possible sources of ‘time inconsistency’ of environmental policies (Brunner *et al* (2012)). First, there may be missing policy instruments, so that environmental policy is used to address more than one objective, for example equity issues as well as environmental issues, and this trade-off may be different *ex post* than *ex ante*. As already noted, in this paper we assume that governments have a full range of policy instruments to deal with other market failures, so in our paper this does not provide a rationale for time inconsistency of environmental policy (see Helm *et al* (2003) footnote 1). Second, time inconsistency may arise when nations are involved

⁵ Of course then can be many other policy issues – e.g. equity considerations (Abrego and Perroni (2002)).

⁶ In the case of R&D we assume there is a single firm, so there are no spillover or strategic investment issues, and this firm can fully capture all consumer benefits – so there are no undervaluation effects.

strategically with other nations – for example through trade and environmental spillovers⁷. We deal with a single country so this source of time inconsistency does not arise. Finally, it is sometimes argued that time inconsistency arises if a government commits to a future emission tax rate, firms invest in R&D to cut their emissions, and the government subsequently changes the emission tax because, following the investment, abatement costs have fallen and the government either cuts the emission tax to transfer quasi-rents from firms to consumers (Blackmon and Zeckhauser (1992)) or raises it to induce more abatement (the ‘ratchet’ effect introduced in Downing and White (1986))⁸. However, this argument presupposes that governments are restricted to committing to just a single tax rate. In principle, if a government can commit, it should commit to a *tax policy* that conditions future taxes on abatement costs and hence the investment undertaken by firms. Such a policy can induce the optimal levels of investment and output and is time consistent. Indeed an anticipated reduction in the tax rate may be part of the profit incentive for the firm to innovate⁹.

In this paper we focus on a different source of time-inconsistency, namely the fact that, in democracies, governments are in power for a short period of time. We suppose that current governments accurately reflect the views of the electorate about the long-term consequences of current and future actions, and in particular the emission damages that

⁷ It has been argued that joining an IEA is a form of commitment – but countries can leave IEAs. We discuss this further in the conclusions.

⁸ Further issues arise when the tax influences both emissions and extraction of exhaustible fossil fuels (Sinn (2008), Hoel (2010), Montero (2011)).

⁹ For an exposition of these arguments in the context of industrial policy Ulph & Ulph (2001). In this paper we assume constant marginal damage costs, so the government will not need to condition its emission tax on whether or not the firm has innovated; in a more general version of this paper (Ulph and Ulph (2011)), where marginal damage costs depend on emissions, we ignore this source of time consistency by assuming that with commitment the government conditions its tax rate on whether or not the firm has innovated.

they might cause. We ignore uncertainty about the economy and the environment by assuming that damage costs are known for sure. If the current government were in power forever it would announce a time-path of environmental tax rates¹⁰, and, as we have noted above, the standard argument is that these environmental taxes would induce both the optimal outputs and optimal investment in emissions-reducing R&D.

However we recognize that governments are not in power forever, and, moreover, cannot tie the hands of future governments. This would not be a problem if future governments gave exactly the same weight to environmental damage as the current government, since, absent all other sources of time-inconsistency, they would implement whatever future policies the current government thought optimal, and, once again, a time-path environmental taxes would be the only policy instruments needed to support the optimum. So we assume instead that future governments may place different weights on environmental damages, not because there has been any change in the views of any of the electorate about the importance they attach to environmental damages, but because some unrelated political issue has arisen that brings to power a government that is thought by the electorate to be best able to address this issue but also represents a subset of the electorate that places a different weight on environmental damage than the electorate as a whole. Nevertheless on average future governments give exactly the same weight to environmental damages as the current government, reflecting our assumption that the current government correctly reflects the views of the electorate as a whole. It is the possibility that future governments give different weights to environmental damage costs

¹⁰ Which could in principle be conditioned on any emissions-reducing investment undertaken by the private sector

relative to economic output than current governments that is source of non-commitment in this paper. We assume that the current government and firms may be uncertain about what this weight of a future government might be.

Thus, the absence of commitment means that both the private sector and the current government face uncertainty about future tax rates. We show that this uncertainty about future governments' preferences, and hence the emission taxes they will impose, reduces firms' incentives to invest (see also Stern (2007)). However we show that lack of commitment *increases* the value attached by the Period 1 government to having a cleaner technology that lowers emissions per unit of output, essentially because a cleaner technology makes future output levels less sensitive to variations in the weight attached by future governments to environmental damage, and so makes future outputs deviate less from that which the current government regards as optimal. In order to induce the private sector to undertake the socially optimal investment in the absence of commitment, the Period 1 may need to subsidise R&D. In addition, we show that the more likely it is that future governments may attach significantly different weights to environmental damages than the current government the larger will be the optimal subsidy.

2. The Model

There is a single firm which produces a commodity the production/consumption of which generates pollution. Let $x \geq 0$ denote output; $e > 0$ emissions per unit of output, and $E = e.x$ total emissions (we ignore abatement to capture the idea that the important way to reduce emissions is through emission-reducing innovation).

There are two periods. In period 1 the firm decides whether or not to make a *large* investment with fixed cost $F > 0$ in an environmental R&D project the sole benefit of which is to produce a cleaner technology. If the firm makes the investment, emissions per unit of output will be $e_L > 0$, but if it does not, emissions per unit of output will remain at the higher level $e_H > e_L$, so that this investment makes a *radical* (i.e. non-marginal) change in emissions per unit of output. With a single firm there are no R&D spillovers and so there is no need for a policy instrument to correct that potential distortion. All the consumer benefits and environmental damage created by this firm accrue in period 2 and discounting is incorporated into the benefit and damage functions discussed below. It may seem odd that in a model designed to capture a stock externality such as greenhouse gases we assume emissions and damage occur only in one period. Our rationale is to focus on the idea that the key to reducing future environmental damage is innovation. We discuss this further in the concluding section.

In period 2 the firm chooses output, x , which yields consumer benefits $B(x) > 0$ (net of production costs), $B'(x) > 0$, $B''(x) < 0$. To capture the idea that consumers are reluctant to cut back consumption we assume that demand is inelastic:

$$0 < \varepsilon(x) \equiv -\frac{B'(x)}{xB''(x)} < 1. \quad (1)$$

To abstract from any competition issues arising from the potential exercise of monopoly power by this firm, we assume that the firm can perfectly price discriminate and thus capture consumer benefits $B(x)$.

We assume a linear environmental damage cost function¹¹:

$$D(E) \equiv \delta E, \quad \delta > 0. \quad (2)$$

Governments are in power for a single period and set policy only for the period in which they are in power and only in relation to decisions made by the firm in that period; in their objective functions they attach a weight ω to environmental damages relative to net consumer benefit. The government in period 1, which, without loss of generality, we assume has weight $\omega = 1$, cares about benefits and costs over both periods. However the only decision by the firm that the period 1 government can influence is whether or not it invests in R&D, and its only instrument is a lump-sum R&D subsidy S . The government in period 2, which may have weight $\omega \neq 1$, cares only about consumer benefits and damage costs in period 2 and can influence only the level of output, and hence emissions, chosen by the firm in period 2, which it does by a tax t per unit of emissions. The value of t chosen by the period 2 government depends on both its weight on environmental damages, ω , and on emissions per unit of output, and hence on the R&D decision made by the firm in period 1.

In this paper we say that the government in period 1 can commit if, in period 1, both it and the firm know for sure that the weight given to damages by the period 2 government is $\omega = 1$, so, in this sense, the ‘same’ government chooses both the period 1 R&D policy and the period 2 environmental policy. The government in period 1 cannot commit if both it and the firm recognize that the period 2 government may put a weight $\omega \neq 1$ on damage costs. We assume that they have a common probability density function $f(\omega) > 0$,

¹¹ In Ulph and Ulph (2011) we show that all the major results of the paper go through for the more general case of non-decreasing marginal damage costs.

defined over an interval $[0, \bar{\omega}]$, $\bar{\omega} > 1$, for the value this weight might take, and that $E(\omega) = 1$ - the expected weight on environmental damages of the future government is the same as that of the current government. Taken together these assumptions capture the idea discussed in the introduction that the fact that future governments might place a different weight on environmental damage from that of the current government :

- just reflects political cycles bringing different governments to power for reasons uncorrelated with the state of the economy or the environment;
- is not because of learning about the true state of the economy or the environment;
- is not because with either government places the “wrong” weight on environmental damage; on average both governments correctly capture the views of the electorate on the long-term environmental damages the country faces.

The implication of lack of commitment is uncertainty about future government’s weight on environmental damage costs, rather than a systematic difference in weights between current and future governments

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3. Analysis of the Model

We determine first the decisions of the government and firm in period 2 and then work backwards to determine the decisions of the government and firm in period 1.

3.1 Period 2: Output Decisions

Assume the second-period government has a weight, ω , on environmental damages, and that, as a result of its period 1 R&D decision, the firm’s technology has emissions e per unit of output. The period 2 government’s payoff is $B(x) - \omega D(ex) = B(x) - \omega \delta ex$. Let

$\hat{x}(e, \omega)$ be the output level that maximizes this payoff and $\hat{E}(e, \omega) = e \cdot \hat{x}(e, \omega)$ the associated level of total emissions. The first-order condition for the optimum output (marginal benefit equals marginal damage cost) is:

$$B'[\hat{x}(e, \omega)] = e \cdot \omega \cdot \delta \quad (3)$$

From (1) and (3) the comparative static elasticities for output and emissions are:

$$0 < -\frac{e \partial \hat{x}}{\hat{x} \partial e} = \hat{\varepsilon} < 1; \frac{e \partial \hat{E}}{\hat{E} \partial e} = 1 + \frac{e \partial \hat{x}}{\hat{x} \partial e} = 1 - \hat{\varepsilon} > 0; \frac{\omega \partial \hat{E}}{\hat{E} \partial \omega} = \frac{\omega \partial \hat{x}}{\hat{x} \partial \omega} = -\hat{\varepsilon} < 0 \quad (4)$$

Where, for notational simplicity, $\hat{\varepsilon} = \varepsilon[\hat{x}(e, \omega)]$ denotes the value of the demand elasticity in (1) at the optimal level of output.

Higher emissions per unit of output lead to lower output, but, with inelastic demand, output falls less than proportionately, so total emissions increase. Only by moving to a cleaner technology can governments reduce total emissions. Governments that care more about the environment want lower levels of output and emissions.

To induce the profit-motivated firm to choose the optimal output level the second-period government sets an emission tax equal to marginal environmental damage costs. Let

$$\Pi(e, t) = \underset{x}{\text{MAX}} [B(x) - tex] \quad (5)$$

$$\tilde{x}(e, t) = \underset{x}{\text{ARGMAX}} [B(x) - tex] \quad (6)$$

be, respectively, the maximum period 2 profits and the associated profit-maximising level of output of the firm when it faces an emissions tax $t \geq 0$ and its emissions per unit of output are e . The first-order condition for profit-maximisation is

$$B'[\tilde{x}(e,t)] = t.e . \quad (7)$$

It follows from (3) and (7) that if the government sets an optimal emission tax,

$$\hat{t}(\omega) = \omega\delta \quad (8)$$

then the firm will be induced to choose the optimal level of output:

$$\tilde{x}(e, \hat{t}(\omega)) = \hat{x}(e, \omega) \quad (9)$$

Equation (8) captures how the emissions tax rate chosen in Period 2 will vary with the weight, ω , placed by the Period 2 government on environmental damage¹².

3.2 Period 1: R&D Decisions.

In the first period the only decision to be made by the firm is whether or not to undertake the R&D investment. The only decision to be made by the government is how to use its R&D policy instruments to align the firm's investment decision with that which it regards as socially optimal. In making these decisions it is assumed that both the firm and the Period 1 government anticipate how the emissions tax will vary with the weight the Period 2 government attaches to environmental damage costs as shown in equation (8).

3.2.1 Commitment

In this case both the firm and the government are certain that the government in period 2 gives a weight $\omega = 1$ to environmental damage costs. Let

$$\hat{W}^c(e) \equiv \underset{x}{\text{MAX}} [B(x) - \delta ex] \equiv B[\hat{x}(e,1)] - \delta e\hat{x}(e,1) \quad (10)$$

¹² In the more general case of a convex damage function the optimal tax may also depend on the emissions technology used by the firm in Period 2 and hence on R&D in Period 1; see Ulph and Ulph (2011)

denote the net benefits the period 1 government anticipates arising in period 2 if emissions per unit of output are e and, in period 2, a government with the same weight on environmental damages as itself sets the emissions tax to maximize its payoff. Similarly,

$$\hat{\Pi}^c(e) \equiv \Pi(e, \hat{t}(1)) = B[\tilde{x}(e, \hat{t}(1))] - \delta e \tilde{x}(e, \hat{t}(1)) \quad (11)$$

denotes the maximum period 2 profits the firm will earn with emissions per unit of output e and an emission tax set by a government with weight $\omega = 1$ on environmental damages. Since, from (9), $\tilde{x}(e, \hat{t}(1)) = \hat{x}(e, 1) \quad \forall e$, equations (10) and (11) establish that $\hat{W}^c(e) = \hat{\Pi}^c(e) \quad \forall e$, so optimal tax policy by a Period 2 government that has the same welfare weight as the Period 1 government aligns the firm's profits with the Period 1 governments objective for any level of emissions per unit of output.

Furthermore if we define $\Delta\hat{\Pi}^c \equiv \hat{\Pi}^c(e_L) - \hat{\Pi}^c(e_H)$ and $\Delta\hat{W}^c \equiv \hat{W}^c(e_L) - \hat{W}^c(e_H)$ as the increase in profits and welfare that, in period 1, the firm and the government respectively anticipate from the R&D when they know for sure that the government in Period 2 places a weight $\omega = 1$ on environmental damage costs, then it follows that $\forall e_H, e_L \quad \Delta\hat{\Pi}^c = \Delta\hat{W}^c$. Since it will be in the interests of the firm (resp. Period 1 government) for the R&D investment to be undertaken if and only if $\Delta\hat{\Pi}^c \geq F$ (resp. $\Delta\hat{W}^c \geq F$), then we have proved:

Proposition 1. If commitment is possible, so that the government in Period 2 implements for sure an emissions tax policy $\hat{t}(1)$ in period 2, then for all $e_H, e_L \quad \Delta\hat{\Pi}^c = \Delta\hat{W}^c$ and so (i) the private and social benefits from having the R&D

investment undertaken are identical, and (ii) the private decision as to whether or not to undertake investment implements the social decision as to whether or not it should be undertaken.

This just illustrates the conventional wisdom that, in the absence of other market failures, the optimal emission tax will induce optimal investment in emissions-reducing R&D.

3.2.2 No Commitment

When there is no commitment both the Period 1 government and the firm have to anticipate that the emission taxes set in period 2 may be chosen by a Period 2 government that gives a weight $\omega \neq 1$ to environmental damage costs. We first assess the implications for the firm.

The firm's period 2 profits when emissions per unit of output are e and the emission tax policy is chosen by a Period 2 government with weight ω on environmental damage costs are:

$$\Pi^n(e, \omega) \equiv \Pi[e, \hat{t}(\omega)] = B[\hat{x}(e, \omega)] - \omega \delta e \hat{x}(e, \omega) = \underset{x}{MAX} B(x) - \omega \delta e x. \quad (12)$$

Consequently the firm's incentive to invest in R&D in order to lower its emissions per unit of output from e_H to e_L is

$$\Delta \Pi^n(\omega) = \Pi^n(e_L, \omega) - \Pi^n(e_H, \omega). \quad (13)$$

It is clearly the case that:

- i. $\Delta \Pi^n(0) = 0$ since no emissions tax is imposed and the optimal output is the same whatever level of emissions is chosen;

ii. $\Delta\Pi^n(1) = \Delta\Pi^c > 0$.

Furthermore, if we differentiate (13) w.r.t ω we get:

$$\frac{d\Delta\Pi^n(\omega)}{d\omega} = \delta[e_H\hat{x}(e_H, \omega) - e_L\hat{x}(e_L, \omega)] = \delta[\hat{E}(e_H, \omega) - \hat{E}(e_L, \omega)] \quad (14)$$

which, from (4), is strictly positive. So, as we would expect, the incentive to invest in emissions-reducing R&D is a strictly increasing function of the weight that the Period 2 government places on environmental damage.

Finally, if make the additional assumption that the demand elasticity, $\varepsilon(x)$ is independent of x with $\varepsilon(x) = \varepsilon \quad \forall x$ then, by differentiating (14) w.r.t. ω we get:

$$\frac{d^2\Delta\Pi^n(\omega)}{d\omega^2} = -\frac{\varepsilon\delta}{\omega}[\hat{E}(e_H, \omega) - \hat{E}(e_L, \omega)] < 0 \quad (15)$$

so the incentive of the firm to undertake emissions-reducing R&D is a strictly increasing and strictly concave function of ω . The intuition is that the emission taxes increase with the weight the Period 2 government places on damage costs, increasing the incentive to innovate, but they do so at a decreasing marginal rate because the firm responds by cutting emissions.

Turning now to the Period 1 government, let

$$W^n(e, \omega) = B[\hat{x}(e, \omega)] - \delta e\hat{x}(e, \omega) \quad (16)$$

be the payoff that the government in period 1 anticipates arising in period 2 when the firm has a technology with emissions per unit of output e and the period 2 policies will be implemented by a government with weight ω on environmental damage costs. Obviously:

$$W^n(e,1) = \hat{W}^c(e) \quad \forall e > 0, \quad (17)$$

while from (3) and (4) it follows that:

$$\frac{\partial W^n(e, \omega)}{\partial \omega} = (\omega - 1) \delta e \cdot \frac{\partial \hat{x}(e, \omega)}{\partial \omega} \Rightarrow \frac{\partial W^n(e, \omega)}{\partial \omega} \begin{matrix} > \\ < \end{matrix} 0 \text{ as } \omega \begin{matrix} < \\ > \end{matrix} 1. \quad (18)$$

Thus, for any technology, the period 1 government's payoff is maximized when it anticipates that future governments will act like it.

We are interested in how the increase in welfare that the period 1 government gains from R&D, $\Delta W^n(\omega) \equiv W^n(e_L, \omega) - W^n(e_H, \omega)$, varies with ω . We know that $\Delta W^n(1) = \Delta W^c$, while, from (14), it follows that

$$\frac{d\Delta W^n(1)}{d\omega} = 0. \quad (19)$$

Furthermore it can be shown that¹³ $\Delta W^n(0) > \Delta W^n(1) > 0$. This suggests that $\Delta W^n(\omega)$ might take a minimum when $\omega = 1$. To investigate this possibility we first consider the increase in welfare that the period 1 government gains from a marginal reduction by the firm in its emissions per unit of output. This is given by

$$-\frac{\partial W^n(e, \omega)}{\partial e} = \hat{x}(e, \omega) \delta [1 + (\omega - 1) \hat{\varepsilon}]. \quad (20)$$

¹³ Let $\hat{x}^0 \equiv \underset{x}{\text{ARGMAX}} B(x)$ so $\hat{x}(e, 0) = \hat{x}^0$. Then: $\hat{x}(e_H, 1) < \hat{x}(e_L, 1) < \hat{x}^0$,

$\Delta W^n(0) = [B(\hat{x}^0) - e_L \hat{x}^0] - [B(\hat{x}^0) - \delta e_H \hat{x}^0] = \delta \hat{x}^0 (e_H - e_L) > 0$, and

$\Delta W^n(1) = \{B[\hat{x}(e_L, 1)] - \delta e_L \hat{x}(e_L, 1)\} - \{B[\hat{x}(e_H, 1)] - \delta e_H \hat{x}(e_H, 1)\}$. Given concavity of $B(x)$ it follows that:

$\Delta W^n(1) < B'[\hat{x}(e_H, 1)]\{\hat{x}(e_L, 1) - \hat{x}(e_H, 1)\} + \{\delta e_H \hat{x}(e_H, 1) - \delta e_L \hat{x}(e_L, 1)\}$

$= \delta e_H \{\hat{x}(e_L, 1) - \hat{x}(e_H, 1)\} + \{\delta e_H \hat{x}(e_H, 1) - \delta e_L \hat{x}(e_L, 1)\} = \delta \hat{x}(e_L, 1)(e_H - e_L) < \delta \hat{x}^0 (e_H - e_L) = \Delta W^n(0)$

If we now make the additional assumption that the demand elasticity, $\varepsilon(x)$ is independent of x with $\varepsilon(x) = \varepsilon \quad \forall x$ then, differentiating (20) w.r.t. ω and using (4), yields:

$$-\frac{\partial^2 W^n(e, \omega)}{\partial \omega \partial e} = \delta \varepsilon (1 - \varepsilon) \hat{x}(e, \omega) [1 - (1/\omega)] \quad (21)$$

So the Period 1 government's marginal gain from the firm's reducing its emissions per unit of output is a decreasing function of ω when $\omega < 1$, reaches a minimum when $\omega = 1$, and is an increasing function of ω when $\omega > 1$. Thus the greater the difference between the weight that a Period 2 government places on environmental damages and the weight of the Period 1 government, the greater is the gain to the Period 1 government from having the firm reduce its emissions per output. The intuition is as follows. From (8) we know that tax per unit of emissions in Period 2 is $\hat{t}(\omega) = \omega \delta$. However the level of output chosen in Period 2 depends on the effective tax per unit of output which is $\omega \delta e$. So the lower are emissions per unit of output the less this tax rate will vary with ω , and so the less will output vary from that which the period 1 government regards as optimal. Hence, the more the weight the Period 2 government varies from the weight the Period 1 government places on environmental damages, the greater is the desire of the Period 1 government to have the firm reduce its emissions.

Note that it is more difficult to make precise statements about the first-order and second-order properties of $\Delta W^n(\omega)$ than those of $\Delta \Pi^n(\omega)$. The reason is that the firm chooses its optimal level of output in response to Period 2 government policies, so when looking at first order effects we can use the envelope theorem to ignore the induced effects of

Period 2 policy on the firm's output. By contrast, the output chosen by the firm will not be that which the Period 1 government would wish the firm to choose. So even first-order effects depend on how output varies with ω .

To get a more complete understanding of $\Delta W^n(\omega)$ and how it relates to $\Delta \Pi^n(\omega)$, in the rest of this paper we again make *the assumption that the demand elasticity, $\varepsilon(x)$ is independent of x with $\varepsilon(x) = \varepsilon \quad \forall x$* . So we assume the demand function is:

$$B(x) \equiv B_0 + \frac{B_1}{1-\beta} x^{1-\beta} \quad (22)$$

where $B_0 > 0, B_1 > 0, \beta > 1$ and so $\varepsilon = 1/\beta < 1$. It is assumed that B_0 is sufficiently large that $B(x) > 0$ for all x . It is straightforward to show that:

$$\Delta \Pi^n(\omega) = \eta(\varepsilon)\omega^{1-\varepsilon} \quad (23a)$$

$$\Delta W^n(\omega) = \eta(\varepsilon)[\varepsilon\omega^{1-\varepsilon} + (1-\varepsilon)\omega^{-\varepsilon}]^{14} \quad (23b)$$

where $\eta(\varepsilon) \equiv \frac{B_1^\varepsilon \delta^{1-\varepsilon}}{1-\varepsilon} (e_H^{1-\varepsilon} - e_L^{1-\varepsilon})$. The key features of these functions are set out in the following Lemma, and illustrated in Figure 1.

Lemma

(i) $\Delta W^n(\omega)$ takes a minimum, $\Delta W^n(1) = \Delta W^c = \eta(\varepsilon)$, at $\omega = 1$ and is *convex* over an interval $[0, \tilde{\omega}]$ where $\tilde{\omega} > 2$; $\Delta W^n(\omega) \rightarrow \infty$ as $\omega \rightarrow 0$; for $\omega > \tilde{\omega}$, $\Delta W^n(\omega)$ is increasing and concave.

¹⁴ As can be seen from (23b) and is illustrated in Figure 1, one consequence of our assumption of a constant elasticity is that when $\omega = 0$ the optimal output is infinite which is why $\Delta W^n(\omega) \rightarrow \infty$ as $\omega \rightarrow 0$.

However, as shown in footnote 11, the result that $\Delta W^n(0) > \Delta W^n(1)$ is general and does not depend on this particular functional form.

(ii) $\Delta\Pi^n(\omega)$ is strictly increasing and *concave*; $\Delta\Pi^n(0) = 0$; $\Delta\Pi^n(1) = \Delta\Pi^c = \eta(\varepsilon)$.

(iii) $\Delta W^n(\omega) \geq \Delta\Pi^n(\omega) \Leftrightarrow \omega \leq 1$.

Proof: The proof is in an Appendix available from the authors.

The intuition for (i) was given above in our discussion following equation (21); the intuition for (ii) was given above in our discussion following equation (15).

Given the absence of commitment, both the firm and the Period 1 government recognize that in Period 2 there could be a government that gives a weight $\omega \neq 1$ to environmental damage. We assume that, in Period 1, both the Period 1 government and the firm are uncertain about the precise type of Period 2 government that will be in power (i.e. they are uncertain about what value ω will take), and that this uncertainty is represented by the *common* probability density function $f(\omega) \geq 0$ defined over $[0, \bar{\omega}]$, $\bar{\omega} > 1$, with $f(\omega) > 0 \quad \forall \omega \in (0,1)$ and $E(\omega) = 1$. So future governments might place a higher or lower weight on environment damage than the current government, but, on average, give exactly the same weight to damage costs as the current government. We then have:

Proposition 2

Uncertainty regarding the weight placed on damage by future governments:

(i) increases the welfare gains of the Period 1 government from the firm's R&D:

$$E[\Delta W^n(\omega)] > \Delta W^n(1) = \Delta \hat{W}^c;$$

(ii) reduces the firm's incentive to undertake R&D: $E[\Delta\Pi^n(\omega)] \leq \Delta\Pi^n(1) = \Delta \hat{\Pi}^c$.

(iii) $E[\Delta W^n(\omega)] > E[\Delta \Pi^n(\omega)]$

Proof:

(i) Follows from the fact that, as shown in Lemma (i)

$$\Delta W^n(\omega) > \Delta W^n(1) \quad \forall \omega \neq 1;$$

(ii) Follows from the fact that $\Delta \Pi^n(\omega)$ is strictly concave.

(iii) Follows from (i) and (ii) and Proposition 1.

If we now take account of the fixed costs of R&D, F , then Proposition 2 raises three possible policy outcomes:

(i) if $E[\Delta W^n(\omega)] > E[\Delta \Pi^n(\omega)] \geq F$, without any intervention by the government the firm will undertake R&D which the government also regards as worthwhile;

(ii) if $F > E[\Delta W^n(\omega)] > E[\Delta \Pi^n(\omega)]$ then the firm will not wish to undertake R&D and the government will not wish to intervene in that decision;

(iii) if $E[\Delta W^n(\omega)] \geq F > E[\Delta \Pi^n(\omega)]$ then in the absence of policy intervention the firm will not undertake the R&D but the government will wish it to undertake the R&D; the government can achieve this by offering an (absolute) R&D subsidy equal to $F - E[\Delta \Pi^n(\omega)]$.

To implement the above decisions rules, the government needs to know F . If this is private information to the firm then the government can still induce the correct investment decision by the firm by aligning the social and private returns to R&D through an (absolute) R&D subsidy $E[\Delta W^n(\omega)] - E[\Delta \Pi^n(\omega)]$. Thus we have established:

Proposition 3

- (i) If the Period 1 government can observe F and if $E[\Delta W^n(\omega)] \geq F > E[\Delta \Pi^n(\omega)]$ then it is optimal for the government to introduce an (absolute) R&D subsidy $S(F) = F - E[\Delta \Pi^n(\omega)]$;
- (ii) If the Period 1 government cannot observe F then it can always ensure that the firm makes the right R&D decision by introducing an (absolute) R&D subsidy $\bar{S} = E[\Delta W^n(\omega)] - E[\Delta \Pi^n(\omega)] > 0$.
- (iii) $S(F) \leq \bar{S}$ with equality if $F = E[\Delta \Pi^n(\omega)]$

This establishes the key result of this paper: if governments are unable to commit to future environmental policies, in the sense that today's agents (the current government and firms) cannot be sure what weight future governments might attach to environmental damage costs, then this lack of commitment can justify current governments subsidizing environmental R&D.

3.2.3 Some Numerical Illustrations

While Proposition 3 establishes the case for an R&D subsidy when governments cannot commit to future environmental policies, an obvious issue is how large might such a subsidy need to be. To answer this question, we focus on the subsidy \bar{S} , use the functional forms in (23), and assume that ω is distributed symmetrically over the range $[0,2]$ around the mean $\omega = 1$ with either a uniform density function, or a triangular density function. The uniform density has more 'weight in the tails' than the triangular density.

Finally to relate these subsidies to potentially observable financial magnitudes we express the resulting subsidies as proportions of $\Delta\Pi^c$ - the profits the firm would make from undertaking R&D if the government could commit. Denote these subsidies (as proportions of $\Delta\Pi^c$) by S^U, S^T . We show in the Appendix that these depend on the value of the demand elasticity, ε , through the formulae:

$$S^U(\varepsilon) \equiv \frac{2^{-\varepsilon} \varepsilon}{2 - \varepsilon}; \quad S^U(0) = 0; \quad S^U(1) = 0.5 \quad (24)$$

$$S^T(\varepsilon) = \frac{2}{(2 - \varepsilon)(3 - \varepsilon)} [(1 + \varepsilon)2^{1-\varepsilon} - 2]; \quad S^T(0) = 0; \quad S^T(1) = 0. \quad (25)$$

Figure 2 shows the values of these subsidies (as percentages of $\Delta\Pi^c$) for values of ε lying between 0 and 1. With the uniform density, the required subsidy rises from 0% to 50% of the commitment level of profit gain from R&D as the elasticity of demand, ε , rises from 0 to 1; in the mid-range of values for the elasticity of demand, $0.25 \leq \varepsilon \leq 0.75$ the subsidy level, S^U , lies between 12% and 36%. For the triangular density, the required subsidy tends to zero as the elasticity of demand tends to 0 or 1; in the mid-range of values for the demand elasticity, $0.25 \leq \varepsilon \leq 0.75$ the subsidy lies between 4% and 7%.

For both density functions, these are non-negligible levels of subsidy, but it is clear that the subsidies depend crucially on the precise shape of the density function. If Period 2 governments are on the whole quite like the Period 1 government – the triangular density – then the subsidy is much smaller than the case of a uniform density where there is more

weight in the tails, and so a much greater likelihood of Period 2 governments that are very different from the Period 1 government.

4. Conclusion

We have shown that the inability of governments to commit to future policies challenges the traditional prescription that environmental policies alone are sufficient to induce optimal emissions and optimal investment in R&D. This is because the inability of the current government to commit to future emission taxes increases the wish of the current government that firms undertake the investment but reduces firms' incentives to invest.

Lack of commitment arises because governments are in power for short periods of time; have to tackle very long-lasting problems such as climate change; but cannot tie the hands of future governments. In this situation a current government faces the possibility that future governments may place a different weight on environmental damage than they do, and this for reasons entirely unrelated to the underlying economic and environmental conditions – since otherwise policies could be conditioned on these and future like-minded governments would implement them.

We show that in these cases uncertainty about the relative weight placed on environmental damage by future governments raises the value attached by the current government to have emissions-reducing R&D undertaken, though lowering the incentives of the private sector to undertake such investment. As a result it can be optimal to introduce an R&D subsidy in circumstances where, if there were no commitment

problems such a subsidy would be unnecessary. Our numerical results show that the required subsidies are not trivial, and depend critically on the shape of the probability distribution of future governments' weights (on environmental damages) relative to those of the current government. The more likely it is that future governments could be very different from the current government, the higher is the required subsidy.

In demonstrating this result we have employed a very simple model. One issue is whether there may be other mechanisms by which a current government could make commitments, avoiding the need for an R&D subsidy. A number of such possibilities have been proposed in the literature: delegation of environmental policy to an independent agency, analogous to the independence of central banks in monetary policy, (Helm *et al* (2003)); using tradable permits linked to a financial instrument with a put option which guarantees a floor to the future price for permits (Ismer and Neuhoff (2009)). However, neither is straightforward (see Brunner *et al* (2012) for an excellent discussion of the relative merits of such commitment devices), particularly in the context of a long-term problem such as climate change. For example, as we have shown¹⁵, any future emission tax or permit price should be made contingent on what innovation has been carried out, so defining an appropriate floor price could be difficult; while delegation has been successful for short-term monetary policy, it would be more problematic for long-term environmental problems. Ultimately future governments could disband any such devices. A subsidy to environmental R&D by current governments is arguably a more secure way of offsetting industry's concerns about investing in such projects.

¹⁵ In a more general companion paper, Ulph & Ulph (2011).

A second issue is how robust our results would be in a richer model. There are a number of possible extensions.

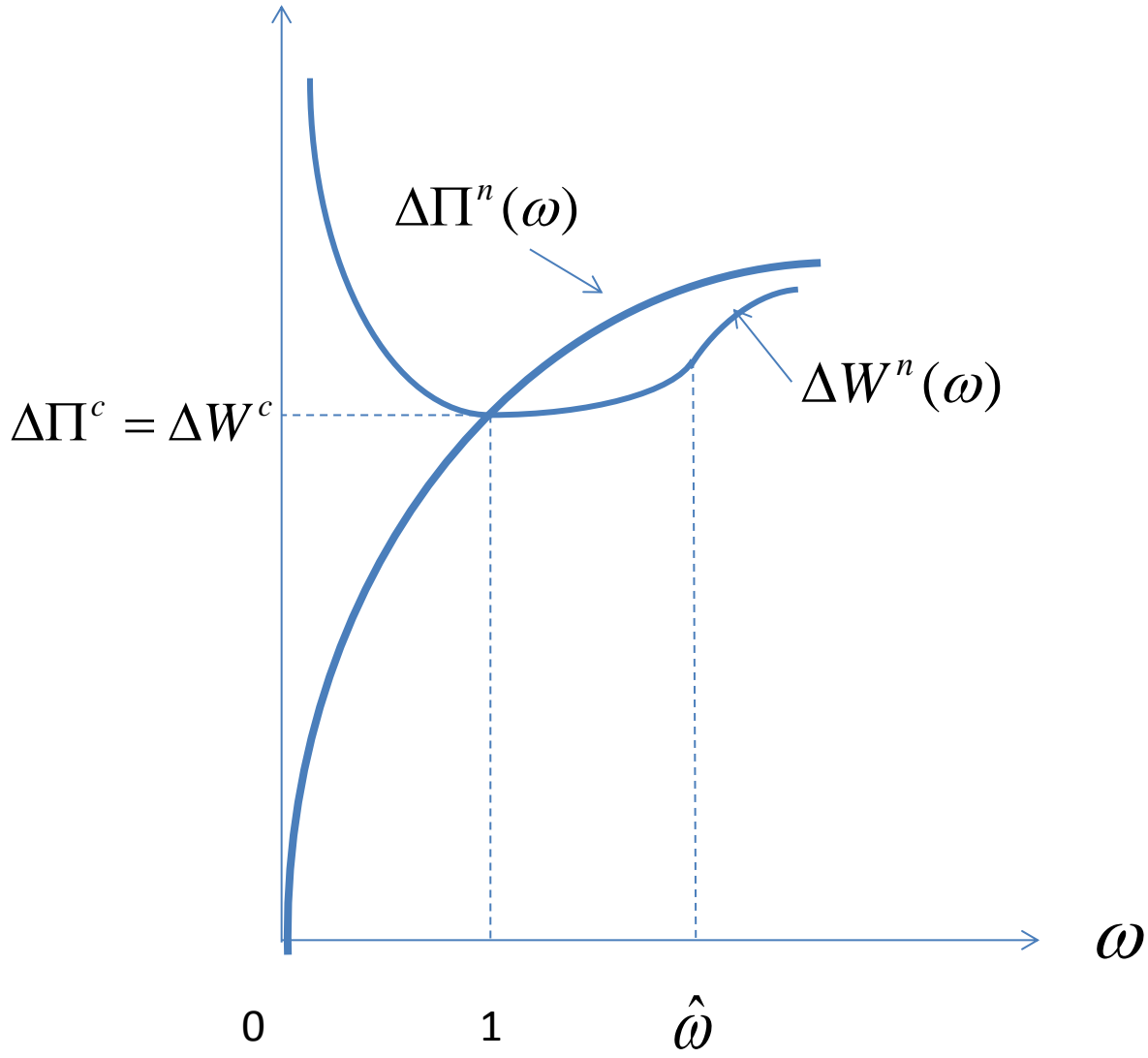
- One obvious extension would be to model a proper stock-externality problem with emissions also in Period 1; it is an interesting conjecture whether this could lead the Period 1 government to set too low an emission tax in Period 1 to force the Period 2 government to take more action.
- A further extension would be to study a multi-country problem and consider whether joining an IEA gives a form of commitment to future emissions policy.
- Thirdly we have ignored intrinsic uncertainty about the climate change process with the related issue of how the possibility of getting better information in the future about climate change damages affects current period policy in a world where governments cannot commit.
- Finally we have assumed that there is just a single firm who is able to capture all the consumer surplus. Montero (2011) explores some of the time-inconsistency problems that can arise even if there is a single government. So it is an open question as to how this interacts with the commitment issues analysed here. Of course when there are many firms there can be additional R&D market failures arising from spillovers.

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Figure 1: $\Delta\Pi^n(\omega)$ and $\Delta W^n(\omega)$



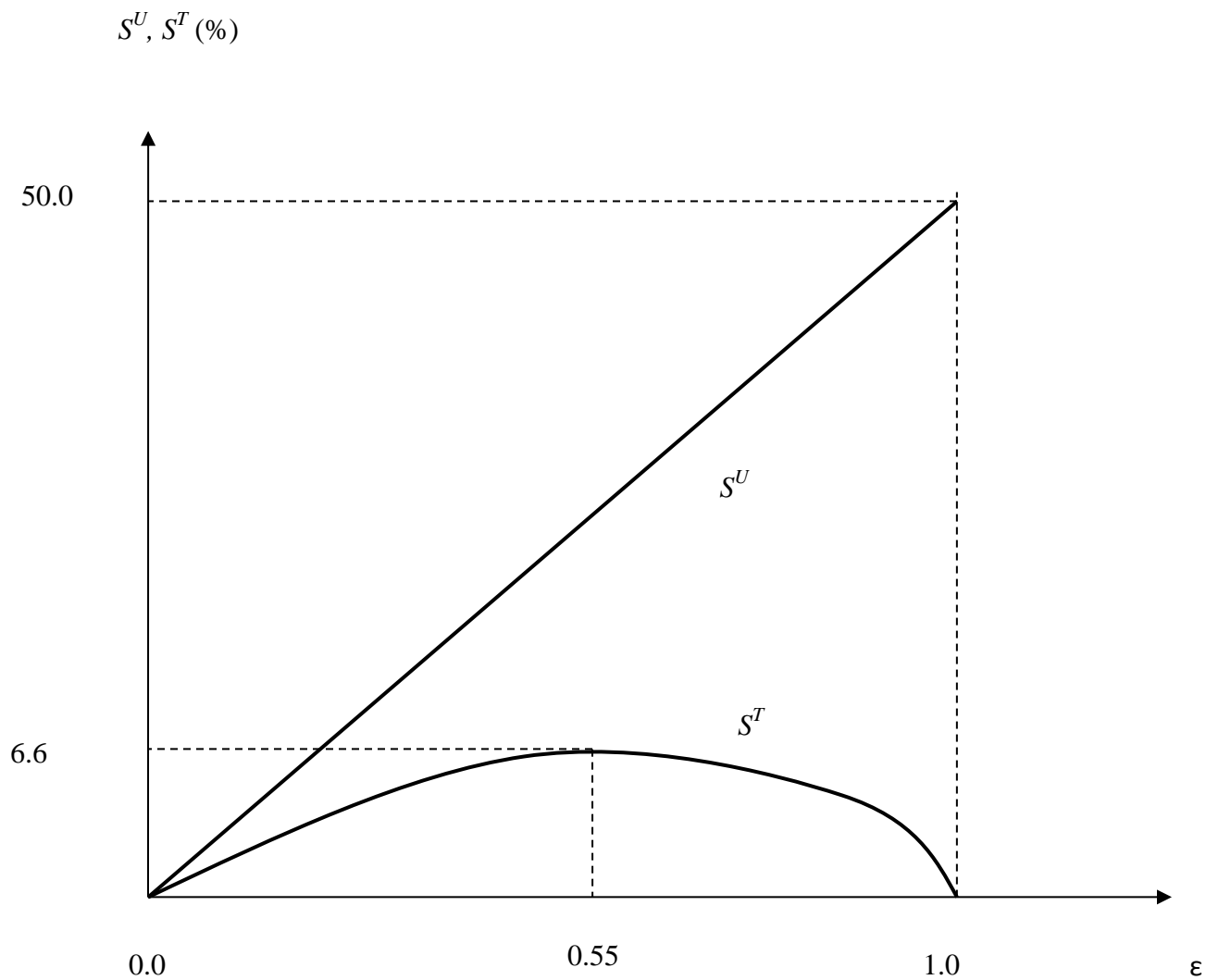


Figure 2: Required Subsidies with Uniform and Triangular Density Functions as Functions of Demand Elasticity