Strategic Incentives for Early Movers in Sequential Climate Games

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Abstract

Free-rider incentives can undermine the provision of a global public good, such as climate change mitigation. Even if a global climate regime or domestic legislation is implemented with a delay, there can be strategic rationales for early movers to increase their provision of the public good. We use a stylized Stackelberg game to illustrate how R&D spillovers, learning by doing and reduced uncertainty over abatement costs can counteract free-riding behaviour on the international level. On the domestic level early action by 'green groups' with a high preference for environmental quality can influence a regulator's choice of the overall provision level.

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JEL classifications: H44, H87, O30, Q54

1. Introduction

The final declaration adopted at the most recent climate negotiations, COP17 in Durban, calls for a global climate agreement with universally binding targets to enter into force by 2020 (UNFCCC 2011). Until then, measures to reduce greenhouse gas emissions will be of a purely voluntary nature. Nevertheless, some regions, such as the European Union, have acted as early movers by unilaterally adopting climate legislation, even though other regions can be expected to introduce comparable policies only in the future[1]. In a similar vein – but on the domestic level – it can be observed that in some regions first movers with higher preference for environmental quality pursue abatement activities that exceed the requirements of government legislation, which may even be non-existent. Climate policies adopted and foreseen in California – despite lack of climate legislation at the United States federal level – are a particularly prominent case in point.

This article investigates the strategic incentives of such early movers in the international as well as the domestic context. In particular, it aims to shed some light on the following questions: what is the optimal level of public good provision by first movers in climate policy games? Do first movers have an incentive to increase (or reduce) their level of public good provision when taking into account that their choices strategically impact the calculus of followers?

From a methodological point of view, the main innovation provided by this paper is the explicit modelling of a leader-follower dynamic in the framework of a Stackelberg game. This setup deliberately departs from the assumption of a game in which both players simultaneously decide on their moves – which is usually adopted in the literature – in order to examine the strategic incentives of early movers. In such a sequential game, the leader chooses his policy, knowing that the follower's action will be taken with a delay, i.e. he makes his move prior to the follower, but anticipates the latter's reaction when deciding on his optimal strategy.

The first part of this paper (Section 3) investigates international climate policy in a non-cooperative game of sequential moves. The two players can spend their income on either private consumption or abatement of greenhouse gas emissions, which is a global public

[1] See e.g. Hof et al. (2008) for a discussion of such a 'fragmented climate regime'.

good. The latter is modelled as being associated with a second public good which is ‘nested’ or complementary, such as technology R&D, learning-by-doing, or reduced uncertainty. It is shown that recognizing these effects early movers have an incentive to increase their level of abatement (and technology provision) in order to ‘buy down costs’ for followers, thus inducing the latter to provide more abatement, too. The second part of the paper (Section 4) investigates the calculus of first movers with higher environmental preferences in a domestic political economy setting, in which ‘green groups’ may persuade the regulator to implement more stringent and Pareto-improving climate policies by voluntarily providing the public good prior to the adoption of government legislation.

This paper proceeds as follows. Section 2 reviews the literature. Section 3 discusses (i) the strategic role of R&D investments, (ii) the incentive to enhance abatement in presence of learning by doing, and (iii) the role of reducing uncertainty in the international context. Section 4 investigates voluntary public good production by environmentally affine first movers in a domestic political economy setting. Section 5 concludes.

2. Relevant Literature

It is a basic insight of modern economic theory that provision of public goods by the market falls short of the social optimum (Samuelson 1954). It is well-understood that government intervention correcting this market failure and preventing free-riding behaviour is warranted to increase social welfare. At the international level, however, there is no world government to resort to. Thus, the prospect for international cooperation on global public good provision such as greenhouse gas emission reductions appears to be bleak (e.g. Carraro and Siniscalco 1993; Barrett 1994). Yet, as mentioned above, some early movers, as for instance the European Union, have in fact assumed a leadership role for global environmental governance, despite their incentives to act as a free-rider (Vogler and Stephan 2007).

The argument that interdependent abatement cost functions can potentially increase the overall abatement effort in a non-cooperative emissions game was introduced by Heal (1994). Golombek and Hoel (2004) confirm this effect – under specific conditions – using a static model with two countries that choose emissions and technology and where one country has a higher preference for climate policy. Beccherle and Tirole (2010) and Harstad (2009) develop a dynamic framework to argue that if the implementation of a global agreement on emission reductions is delayed, countries face incentives to invest less in abatement technologies early on in order to enhance their bargaining position in future climate negotiations. In the same vein, Urpelainen (in press) argues that countries with low bargaining power have little incentive to invest in technologies, as they expect to capture only a small fraction of the added value of reduced abatement costs in future negotiations. Buchholz and Konrad (1994) point out the strategic incentive to implement more expensive technologies in order to credibly commit to higher mitigation costs, such that other countries react by increasing their respective provision of the public good. Heal and Narui (2010) demonstrate that in a Nash-setting technology spillovers may reduce free-riding depending on the magnitude of these spillovers and the effect of R&D on the marginal abatement costs.

Conceptually, our contribution in the first part of the paper differs from these analyses by adopting a dynamic approach in the sense of a non-cooperative Stackelberg game featuring sequential choices by symmetric countries, and by discussing several effects that lead to increased abatement by first movers within this framework.

In the domestic context, Sinn (2008) argues that voluntary public good provision by first movers such as local communities is not a rational strategy due the presence of government regulation, and carbon leakage (in the sense that other actors reduce their public good supply accordingly). By contrast, Ostrom (2010) maintains that the presence of co-benefits warrants emission reductions on the individual and local level even in absence of top-down regulation.

This paper demonstrates that under specific circumstances voluntary public good provision by groups with higher environmental preferences can serve their self-interest and entail a Pareto-improvement of welfare due to strategic interaction effects with government regulation.

3. Strategic Incentives for Early Movers on the International Level

This section examines strategic incentives for an individual country or region to adopt climate policies, even if policies in other parts of the world experience a delay. For this reason, we investigate the strategic interaction between a leader and a follower in the setting of a Stackelberg-game. In this sequential move game, the leader moves first, while the follower only moves after observing the leader's action. The assumption of an exogenously given sequence of moves seems justified for the issue central to this paper, namely to investigate the strategic incentives of one region (the leader) if climate measures in another region (the follower) are known to be decided with a delay only, e.g. due to political constraints[2]. The analysis focuses on how technology spillovers, learning-by-doing, and decreased uncertainty with regard to abatement costs can ease the follower's incentives to free-ride - and hence act as a motivation for early action by the leader, who anticipates the follower's reaction.

3.1. Free-rider incentives and strategic R&D investments

This section introduces the basic Stackelberg game and identifies the free-riding incentive of the follower regarding the abatement effort of the first mover. It also derives the strategic incentive for enhanced R&D investment by the leader due to recognition of a technology spillover on the follower. In this context, the term 'technology spillovers' means that the leader's development of more advanced (abatement) technologies allows the follower to enjoy a higher level of technology, too (Jaffe et al. 2005a). Jaffe et al. (2005b) emphasize that environmental policy is generally confronted with two market failures, namely the environmental externality and spillovers in technology markets. Numerous mechanisms to explain technology spillovers have been identified in the literature, including trade relations (Coe et al. 1997, Branstetter 2001) and foreign direct investment (Javorcik 2004).

In the following, we examine the strategic implications of technology spillovers in a Stackelberg game, i.e. with countries taking their decisions sequentially. In our model, each actor's preferences can be expressed by a utility function which depends on private consumption *c* and the level of a public good *e* which is jointly provided by *i* agents[3]:

$$u^i(c^i, \sum_i e^i),\ u^i_c > 0;\ u^i_e > 0;\ u^i_{cc} < 0;\ u^i_{ee} < 0;\ u^i_{ce} > 0 \qquad (1)$$

[2] For instance, given the current economic situation and public opinion towards climate change, it appears highly unlikely for the US to implement a national target to reduce greenhouse gas emissions in the near future.

[3] Subscripts denote partial derivatives. The properties stated in (1) hold for a wide range of utility functions, for instance CES or Cobb-Douglas.

Each agent is endowed with initial income I^i. The costs Θ of providing e^i units of the public good *e* are convex in *e*. Further, higher levels of technology *t* lead to lower total as well as marginal costs:

$$\Theta^i = \Theta^i(e^i, t);\ \Theta^i_e > 0;\ \Theta^i_{ee} > 0;\ \Theta^i_t < 0;\ \Theta^i_{et} < 0\,. \qquad (2)$$

Consider the case of two agents: one is the leader, who not only decides about his public good contribution e^l, but can also invest in technological innovation to attain technological level *t* at cost $\vartheta(t)$, $\vartheta_t > 0$. Examples are expenditures for basic R&D or demonstration projects, e.g. for carbon capture and storage (CCS), concentrated solar power (CSP) plants, and electric vehicles. The other actor (who we call 'follower') then decides about his provision e^f taking *t* and e^l as given. There is a technology spillover between the actors that renders the technology a public good. Our formulation does not necessarily mean that the follower's level of technology is identical to the leader's; it is sufficient to state that the follower's total and marginal costs are the lower the more advanced the leader's technology, i.e. $\Theta^f_t < 0;\ \Theta^f_{et} < 0$.

The follower's reaction function with regard to the leader's provision of *e* and *t* is specified by the following proposition:

Proposition 1: The higher the provision of public good e *by the leader, the lower will be the provision of* e *by the follower. The higher the provision of technology* t *by the leader, the higher will be the provision of* e *by the follower.*

<u>Proof</u>: the follower solves the following maximization problem:

$$\max_{e^f, c^f} u^f(c^f, e^l + e^f) \text{ s.t. } I^f = c^f + \Theta^f(e^f, t)\,. \qquad (3)$$

This yields the first order condition:

$$u^f_e - u^f_c \Theta^f_e = 0\,. \qquad (4)$$

Taking total differentials, the follower's budget constraint can be written as:

$$dc^f = -\Theta_e^f de^f - \Theta_t^f dt \qquad (5)$$

Totally differentiating the first order condition results in:

$$u_{ce}^f dc^f + u_{ee}^f (de^l + de^f) - u_{cc}^f \Theta_e^f dc^f - u_{ce}^f \Theta_e^f (de^l + de^f) - u_c^f \Theta_{ee}^f de^f - u_c^f \Theta_{et}^f dt = 0 \qquad (6)$$

Inserting (5) into (6) and rearranging terms yields:

$$\begin{aligned} &de^l [u_{ee}^f - u_{ce}^f \Theta_e^f] + de^f [u_{ee}^f - 2u_{ce}^f \Theta_e^f + u_{cc}^f (\Theta_e^f)^2 - u_c^f \Theta_{ee}^f] \\ &+ dt[u_{cc}^f \Theta_e^f \Theta_t^f - u_{ce}^f \Theta_t^f - u_c^f \Theta_{et}^f] = 0 \end{aligned} \qquad (7)$$

From this expression, we can derive the follower's reaction functions to a marginal change in the leader's choice of *e* and *t* while holding all other variables constant (i.e. setting $dt=0$ and $de^l=0$, respectively):

$$\frac{de^f}{de^l} = \frac{u_{ce}^f \Theta_e^f - u_{ee}^f}{u_{ee}^f - 2u_{ce}^f \Theta_e^f + u_{cc}^f (\Theta_e^f)^2 - u_c \Theta_{ee}^f} \qquad (8)$$

$$\frac{de^f}{dt} = \frac{u_{ce}^f \Theta_t^f - u_{cc}^f \Theta_e^f \Theta_t^f + u_c^f \Theta_{et}^f}{u_{ee}^f - 2u_{ce}^f \Theta_e^f + u_{cc}^f (\Theta_e^f)^2 - u_c \Theta_{ee}^f} \qquad (9)$$

The numerator of the follower's reaction function to the leader's choice of *e* is strictly positive, while the denominator is strictly negative, which proves the first part of Proposition 1. Likewise, both the numerator and the denominator of the follower's reaction function to the leader's choice of *t* are strictly negative, proving the second part of the proposition. □

The next proposition concerns the impact of recognizing technology spillovers on the leader's provision of *t* as well as the total amount of *e*:

Proposition 2: Recognizing technology spillovers increases the leader's optimal amount of technology expenditure compared to the case without spillovers (in which $\Theta_t^f = 0$ *and* $\Theta_{et}^f = 0$*). This increases the overall level of the public good* e *relative to the case without technology spillovers.*

Proof: The leader's maximization problem can be expressed as:

$$\max_{e^l, c^l, t} u^l(c^l, e^l + e^f) \text{ s.t. } I^l = c^l + \Theta^l(e^l, t) + \vartheta(t) . \tag{10}$$

Hence, the leader's first order conditions are:

$$u_e^l \cdot (1 + \frac{de^f}{de^l}) - u_c^l \Theta_e^l = 0 \tag{11}$$

$$u_e^l \cdot \frac{de^f}{dt} - u_c^l \cdot (\Theta_t^l + \vartheta_t) = 0 \tag{12}$$

Proposition 1 establishes that $\frac{de^f}{dt} > 0$. As $u_e^l > 0$ and $u_c^l > 0$ by definition, the term in brackets in (12) must be positive, i.e. $\Theta_t^l + \vartheta_t > 0$. Without the effect of technology spillovers, however, the follower's provision of *e* does not depend on the leader's choice of *t*, i.e. $\frac{de^f}{dt} = 0$ and the leaders chooses the level of technology that minimizes his total costs, such that $\Theta_t^l + \vartheta_t = 0$. At the cost minimum[4], the cost minimization problem has to be convex (i.e. it has to satisfy $\Theta_{tt}^l + \vartheta_{tt} > 0$). As for a convex cost function the locus of positive slopes is located at the right hand side of the cost minimum, *t* must be larger with technology spillovers than in the case without spillovers (cf. Figure 1). Thus, the leader has an incentive to incur higher technology costs in order raise the follower's contribution to *e*.

<< Figure 1 about here >>

[4] For the question under study, only cases in which a cost minimum exists (i.e. in which it is worthwhile to engage in technology development) are of interest. Existence of an inner solution can for instance be ensured by assuming $\lim_{t \to 0} \Theta_t \to -\infty$ and $\vartheta(t = 0) = 0$.

Showing that the total amount of public good *e* is higher with technology spillovers is straightforward: starting from the case without technology spillovers, (7) states that the leader could obtain the identical outcome if spillovers were introduced ($de^f=0$ if $de^l=0$ and $dt=0$). However, as demonstrated above, with technology spillovers it is optimal for the leader to choose a higher level of *t*, which corresponds to lower consumption c^l. Choosing a lower level of consumption can only be an optimum if it is compensated for by a higher total amount of *e*. □

3.2. Learning by doing with spillovers

There is an ongoing economic debate on how to model innovation in low-emission technologies (Edenhofer et al. 2006). An alternative formulation to the model applied in the previous section - in which technology can be understood as a stock of knowledge capital (Keller 2004) - is 'learning by doing', i.e. technology costs that decrease with the amount of abatement activity (Newell et al. 2006). Efficiency improvements in production plant operation and improving knowledge of workers and engineers are specific examples. Thus, policies fostering the deployment of low-emission technologies such as the EU emission trading system (EU ETS) or feed-in tariffs employed e.g. in Germany and other regions are commonly expected to reduce the costs of abatement technology over time. Empirical estimates for wind turbines, for instance, suggest that every doubling of the cumulatively installed capacity reduces electricity generation costs by about 20% (Junginger et al. 2005). Despite some criticism (e.g. Nemet 2006; Nordhaus 2009), most numerical models of climate change economics incorporate the assumption that low-carbon technologies are subject to learning by doing (Popp et al. 2006) [5].

We express learning by doing with spillovers by specifying the follower's total as well as marginal costs of abatement to negatively depend on the level of the leader's provision of *e*:

$$\Theta^l = \Theta^l(e^l);\ \Theta^l{}_{e^l} > 0 \qquad (13)$$

$$\Theta^f = \Theta^f(e^f, e^l);\ \Theta^f_{e^f} > 0;\ \Theta^f_{e^f e^f} > 0;\ \Theta^f_{e^l} < 0;\ \Theta^f_{e^l e^f} < 0 \qquad (14)$$

[5] Also note that Barrett (2006) demonstrates that if R&D costs decrease with the amount of R&D undertaken, a green 'breakthrough' technology is more likely to be adopted and to increase the size of the coalition of countries contributing to the provision of the public good

Proposition 3 states how learning by doing with spillovers influences the follower's reaction function with regard to the leader's provision of *e*:

Proposition 3: If the follower's costs of providing the public good negatively depend on the leader's provision, the former has less incentive to free-ride than in the case without learning by doing (in which $\Theta^f_{e^l} = 0$ *and* $\Theta^f_{e^f e^l} = 0$*). Depending on preferences and technology, learning by doing can turn provision of* e *by the follower from a strategic substitute into a strategic complement to the leader's contribution.*

Proof: As in Eq.(3), the follower's maximization problem is given by:

$$\max_{e^f, c^f} u^f(c^f, e^l + e^f) \text{ s.t. } I^f = c^f + \Theta^f(e^f, e^l) \tag{3'}$$

His first order condition can again be written as:

$$u^f_e - u^f_c \Theta^f_{e^f} = 0 \tag{4'}$$

Taking total differentials then yields:

$$u^f_{ee}(de^f + de^l) + u^f_{ce} dc^f - u^f_{ce}\Theta^f_{e^f}(de^f + de^l) - u^f_c(\Theta^f_{e^f e^f} de^f + \Theta^f_{e^f e^l} de^l) = 0 \tag{15}$$

Using follower's budget constraint $I = c_f + \Theta^f(e^f, e^l)$, we can express dc^f in terms of de^f and de^l:

$$dc^f = -\Theta^f_{e^f} de^f - \Theta^f_{e^l} de^l. \tag{16}$$

Combining (15) and (16) then directly results in the follower's reaction function:

$$\frac{de^f}{de^l} = \frac{u^f_{ee} - 2u^f_{ce}\Theta^f_{e^l} + u_{cc}\Theta^f_{e^f}\Theta^f_{e^l} - u^f_c \Theta^f_{e^f e^l}}{-u^f_{ee} + 2u^f_{ce}\Theta_{e^f} - u_{cc}(\Theta^f_{e^f})^2 + u^f_c \Theta^f_{e^f e^f}} \tag{17}$$

The second, third, and fourth term of the numerator are associated with decreasing costs resulting from the leader's action. All three are positive, which means that – given that the denominator is strictly positive – they raise the follower's provision of *e* compared to the case in which his costs are independent of the leader's action. This means that the follower's incentive to free-ride (which is due to $u^f_{ee} < 0$) is dampened. If the cost reductions triggered by the leader are large enough the slope of the reaction function can become positive such the follower responds to the leader's higher provision of *e* by increasing his own contribution, too. □

The effect of learning by doing on the leader's choice of e and the resulting total level are stated in the proposition below:

Proposition 4: If the follower's costs of providing the public good negatively depend on the leader's provision, the follower's reduced incentive to free-ride raises the leader's provision of e *as well as the overall level of* e *compared to the case without learning-by-doing.*

Proof: The leader's first order condition is:

$$u^l_e \cdot \left(1+\frac{de^f}{de^l}\right) - u^l_c \Theta^l_e = 0\,. \tag{18}$$

This can also be written as:

$$\frac{u^l_e}{u^l_c} = \frac{\Theta^l_e}{1+\dfrac{de^f}{de^l}}\,, \tag{18'}$$

i.e. the leader's marginal rate of substitution between the public and the private good equals their marginal rate of transformation. With decreasing returns to both *c* and *e*, the leader responds to a lower absolute value of $\frac{de^f}{de^l}$ (which Proposition 3 has shown to obtain with learning by doing) by increasing her supply e^l while decreasing c^l to satisfy (18).

As the follower's incentives to free-ride are diminished, his reaction to an increased e^l is less pronounced than in the case in which his costs are independent of the leader's action (cf. Proposition 3). Therefore, both actors contribute more to *e*, such that a higher global level of abatement results. □

3.3. Reducing abatement cost uncertainty

If economic agents are risk-averse uncertainty can seriously undermine investment activity (Aizenman and Marion, 1999). In this context it has also been argued that undertaking a risky investment has some characteristics of a public good: as information regarding a project's feasibility is revealed, the risk incurred by other market participants who consider engaging in a similar type of project is reduced (Hausmann and Rodrik, 2003). For the case of climate change, Kolstad (2007) shows that in a standard emission game with endogenous coalition formation reduced uncertainty over costs and benefits of abatement prior to negotiations increases the size of the coalition. A similar effect exists in our model, where the leader has an incentive to increase public good provision if costs and benefits of abatement are uncertain but cost uncertainty can be reduced via early action. If the follower is risk averse and the leader's action decreases cost uncertainty – i.e. there are knowledge spillovers – the leader has an additional incentive to engage in the production of *e*. In this case, the economic mechanism that shapes the strategic interaction is the public good nature of information about cost uncertainty.

We can model both actors' choices under uncertainty as maximization of expected utility. Consider the case in which abatement costs $\tilde{\Theta}^i$ are uncertain and actors decide on their provision of *e* before uncertainty is resolved. Consumption is determined by the budget constraint $\tilde{c}^i = I^i - \tilde{\Theta}^i(e^i)$ and expected utility becomes:

$$Eu^i = E[u^i(I^i - \tilde{\Theta}^i(e^i), e^i)] \quad (19)$$

Alternatively, expected utility can be expressed in terms of certainty-equivalents, i.e. the level of consumption that would yield the identical utility in the case without uncertainty:

$$E[u^i(I^i - \tilde{\Theta}^i(e^i), e^i)] = u^i(I^i - (1+\sigma^i)\overline{\Theta}^i(e^i), e^i) \qquad (20)$$

Here, $\overline{\Theta}$ denotes the expected value of mitigation costs and σ the risk premium, i.e. the mark-up an actor would be prepared to pay over expected costs to eliminate uncertainty. For $u^i_{cc} < 0$, it follows that σ is strictly positive, and a higher σ decreases the marginal utility derived from e ($u^i_{e\sigma} < 0$, as $u^i_{ce} > 0$), but increases the marginal utility of consumption ($u^i_{c\sigma} > 0$, as $u^i_{cc} < 0$). Let σ^i be a function that depends negatively on the leader's action ($\frac{d\sigma^f}{de^l} < 0$) in the sense that a higher provision of e by the leader reduces the follower's cost uncertainty and consequently her risk premium σ.

Proposition 5: If the follower is risk averse and her uncertainty about the costs of providing the public good negatively depends on the leader's provision, the former has less incentive to free-ride than in the case in which her uncertainty is independent of the leader's action (i.e in which $\sigma^f_{e^l} = 0$). Depending on preferences and technology, reduced uncertainty can turn provision of e *by the follower from a strategic substitute into a strategic complement to the leader's contribution.*

<u>Proof</u>: The follower's first order condition is:

$$u^f_e - (1+\sigma^f)u^f_c\overline{\Theta}^f_e = 0, \qquad (21)$$

Its total differential is given by:

$$u^f_{ee}(de^f + de^l) + u^f_{ce}dc^f + u^f_{e\sigma}\sigma^f_{e^l}de^l - (1+\sigma^f)\overline{\Theta}^f_e u^f_{ce}(de^f + de^l) - (1+\sigma^f)\overline{\Theta}^f_e u^f_{cc}dc^f = 0 \qquad (22)$$

Plugging the total differential of the follower's budget constraint $dc^f = -(1+\sigma^f)\overline{\Theta}^f_e de^f$ into this expression and rearranging terms directly yields the follower's reaction function:

$$\frac{de^f}{de^l} = \frac{u^f_{ee} - (1+\sigma^f)\overline{\Theta}^f_e u^f_{ce} + u^f_{e\sigma}\sigma^f_{e^l}}{-u^f_{ee} + 2(1+\sigma^f)\overline{\Theta}^f_e u^f_{ce} - (1+\sigma^f)^2(\overline{\Theta}^f_e)^2 u^f_{cc}} \qquad (23)$$

The first two terms of the numerator are negative while the third one, which represents the follower's reaction to reduced uncertainty due to the leader's production of *e*, is positive. As the denominator is strictly positive, the numerator's last term decreases free-riding by the follower and can make her reaction function turn positive. In this case, the follower's provision of *e* would be a strategic complement instead of a strategic substitute to the leader's provision. □

Proposition 6: If the follower's uncertainty about the costs of providing the public good negatively depends on the leader's provision, the follower's reduced incentive to free-ride raises the leader's provision of e *as well as the overall level of* e.

Proof: the proof is identical to the proof of Proposition 4 if Θ_e^l is substituted by $(1+\sigma^l)\overline{\Theta}_e^l$. □

4. Strategic incentives of 'green groups' in a domestic setting

While the former sections examined the non-cooperative case of one leader and one follower in the international context – i.e. absent government intervention – we now consider a domestic setting. In addition, asymmetric preferences are introduced with a 'green group' featuring higher preferences for abatement. Such higher preference may derive from different perceptions of the significance and risks of climate change, normative considerations, or from individual differences in net abatement costs due to asymmetric co-benefits such as energy efficiency savings (Ostrom 2010). This group is modelled as the Stackelberg leader who can decide on voluntary public good provision prior to the adoption of regulation by government, which is modelled as the follower. Again, this exogenously given sequence of moves corresponds to a situation in which it is known that implementation of climate measures will be subject to a delay.

Previous literature has frequently portrayed the calculus underlying the voluntary provision of public goods as a moral obligation not to take a free ride if others contribute to a public good (Sudgen 1984), as 'impure altruism' such that utility is derived from the 'warm glow' of giving (Andreoni 1990), or as a signalling device to transmit information regarding wealth or income (Glazer and Konrad 1996). By contrast, we consider a political economy equilibrium where green groups with exogenously higher preference for abatement consider their strategic opportunities for modifying government climate policies by shifting parameters of the regulation game via voluntary early action.

Consider two types of individuals[6] (h-types and l-types) with different preferences for consumption and environmental quality with utility functions u^h and u^l that satisfy (if u^h and u^l have identical arguments):

$$u_c^h(c,e) < u_c^l(c,e) \text{ and } u_e^h(c,e) > u_e^l(c,e) \qquad (24)$$

In the economy there are n^h and n^l individuals of each type, respectively, each endowed with initial income I_0. The government levies taxes, which are evenly spread across the population[7], to finance its provision of the public good *e*. Private actors and the government have identical production technologies for *e* which satisfy:

$$\Theta^i = \Theta^i(e^i);\ \Theta_e^i > 0;\ \Theta_{ee}^i \geq 0\,. \qquad (25)$$

We assume that for h- and l-types no side payments from one group to the other are permitted. The government maximizes a utilitarian social welfare function and decides about the total level of *e* (i.e. its residual provision) after observing the private actors' moves (who take the government's reaction into account when making their decisions).

Proposition 7 examines the incentives of l-types to voluntarily provide *e* in addition to what is already provided by the government:

Proposition 7: With a government aiming at maximizing a utilitarian social welfare function, actors that have a low preference for the public good (l-types) never endeavour in voluntary provision of e.

Proof: In the case of pure government provision (i.e. if no public good is provided by private

[6] This implies the assumption that appropriate mechanisms to ensure collective action within the respective groups are in place.

[7] This assumption can be justified either on informational restrictions (i.e. inability to distinguish between h- and l-types) or equity considerations.

actors), it levies a tax $\frac{\Theta^G}{n^h + n^l}$ and each actor consumes $I_0 - \frac{\Theta^G}{n^h + n^l}$ units of *c*. The social welfare function can then be expressed as:

$$U^S = n^h \cdot u^h (I_0 - \frac{\Theta^G (e^G)}{n^h + n^l}, e^G) + n^l \cdot u^l (I_0 - \frac{\Theta^G (e^G)}{n^h + n^l}, e^G) \qquad (26)$$

The government chooses its provision of *e* (and the correspond taxes) to maximize (26). The first order condition of the government's problem hence is:

$$U^S_{e^G} = n^h \cdot [-u^h_c \cdot \frac{\Theta^G_e (e^G)}{n^h + n^l} + u^h_e] + n^l \cdot [-u^l_c \cdot \frac{\Theta^G_e (e^G)}{n^h + n^l} + u^l_e] = 0 \qquad (27)$$

As by (24) $u^h_c < u^l_c$ and $u^h_e > u^l_e$ the term in the first bracket is unambiguously larger then the one in the second bracket. Therefore, as their weighted sum equals zero, the first term must be positive, and the second one negative. Note that both terms directly correspond to l- and h-types' change in utility from a marginal increase of the government's provision of *e*, i.e. they are equivalent to the total differentials $\frac{du^h}{de^G}$ and $\frac{du^l}{de^G}$. Therefore, $\frac{du^l}{de^G} < 0$ if *e* is provided by the government (and the l-types' bear the share $\frac{n_l}{n_h + n_l}$ of total costs). From this it follows that for l-types the marginal utility of voluntarily providing *e* (in which case they bear the full costs) cannot be positive, and we conclude that $e^l = 0$.□

Proposition 8 inspects the incentives of h-types to engage in the voluntary provision of *e*:

Proposition 8: Raising the total amount of e *through voluntary contributions prior to the adoption of government policy can be desirable for h-types. If voluntary provision of* e *by h-types occurs, it results in a Pareto improvement compared to the case of pure government provision.*

<u>Proof:</u> With voluntary provision of *e* by h-types, their budget constraint becomes

$$c^h = I_0 - \frac{\Theta^G(e^G)}{n^h + n^l} - \frac{\Theta^h(e^h)}{n^h}, \tag{28}$$

i.e. h-types contribute (via taxation) a share that is proportional to the one borne by l-types to the costs of e^G that is provided by the government but face the full costs of their voluntary provision. The government's first order condition then reads (taking into account that $e^l = 0$, as shown in Proposition 7):

$$\begin{aligned} U^S_{e^G} = n^h \cdot [-u^h_c(c^h, e^h + e^G) \cdot \frac{\Theta^G_e(e^G)}{n^h + n^l} + u^h_e(c^h, e^h + e^G)] \\ + n^l \cdot [-u^l_c(c^l, e^h + e^G) \cdot \frac{\Theta^G_e(e^G)}{n^h + n^l} + u^l_e(c^l, e^h + e^G)] = 0 \end{aligned} \tag{29}$$

This allows us to derive the government's reaction function to h-types' contribution to *e*. In the Appendix we show that $\frac{de^G}{de^h}$ is strictly negative. h-types supply some of the public good if it increases their utility compared to the case where the public good is exclusively provided by the government $(e^h = 0)$, i.e. if their marginal utility is positive:

$$\frac{du^h}{de^h} = -u^h_c \cdot \frac{\Theta^h_e(e^h)}{n^h} - u^h_c \cdot \frac{\Theta^G_e(e^G)}{n^h + n^l} \cdot \frac{de^G}{de^h} + u^h_e(1 + \frac{de^G}{de^h}) > 0 \tag{30}$$

The first term is negative and captures the decreased utility from increased costs of privately providing *e*. The second one is positive and related to increased consumption possibilities due to lower taxes (as $\frac{de^G}{de^h} < 0$). Their combined impact is unambiguously negative. The last term captures the (positive) welfare effect of a higher level of environmental quality (assuming that $\frac{de^g}{de^p} > -1$. Otherwise, h-types would never have an incentive to provide *e*, as this would lower their consumption as well as the overall level of *e*).

Hence, h-types have an incentive to privately supply *e* if (i) the additional costs of private provision are not too high compared to government provision (which is the case if n^h is large relative to n^l), (ii) h-types' extra utility from a higher *e* is high relative to the disutility from lower consumption (due to the extra costs of privately providing of e), and (iii) if the absolute value of $\frac{de^G}{de^h}$ is small, i.e. the government's reaction function is relatively flat, such that additional private supply of *e* does not reduce the government's supply by a too large amount.

The last part of the proposition is straightforward: h-types only supply *e* voluntarily if it increases their utility. l-types benefit from a higher level of *e* as well as from lower taxes needed to finance the decreased government provision of *e* such that their utility unambiguously increases, too[8]. □

5. Conclusions

This paper has demonstrated that in simple sequential climate games à la Stackelberg the presence of spillovers may set strategic incentives for early movers to increase their level of public good provision. The basic intuition behind these effects is that early action may 'buy down the costs' of abatement for followers, thus inducing the latter to provide more abatement.

On the international level, when taking into account that abatement of greenhouse gas emissions and technology are complements (enhanced technology reduces the costs of beneficial abatement), a first mover invests more in technology R&D to reduce abatement costs of the late mover, and the total supply of public good provision increases. Further, if provision of abatement by the first mover entails learning by doing effects which spill over to the follower, taking this effect into account increases the public good provision effort of the early mover and leads to an overall increase in public good provision. Finally, if abatement by the first mover reduces the uncertainty over public good provision costs, she has an incentive to provide more of the public good to increase provision by a risk-averse follower.

In the domestic context, if the total amount of public good provision is decided by a central authority with utilitarian welfare function and side payments are not allowed, actors with high preference for the public good can influence the regulator's decision by providing more of the

[8] Note that this result is closely related to the finding by Chichilnisky and Heal (1994) that without transfer payments a globally uniform carbon price is in general not Pareto-optimal

public good prior to adoption of legislation. In doing so, they make Pareto-improving higher overall levels of public good provision acceptable to actors with a lower preference. This effect prevails when the 'green group' is sufficiently large, its preference for abatement relative to consumption is high, and if government does not substantially reduce the stringency of regulation in response to the voluntary provision (i.e. the crowding out effect is low).

Taking into account that climate policy is a sequential game involving technology spillovers, learning by doing, and reduced abatement cost uncertainty for the follower (in the international context), as well as asymmetric preferences for environmental quality (on the domestic level) somewhat alleviates the bleak prospect for the provision of the global public good of greenhouse gas mitigation. Yet, the strategic incentives discussed in this paper crucially depend on the expectation of future climate policies, emphasizing the importance of the political process to uphold the commitment to eventually agree on legally binding emission targets.

References

Aizenman, J. and Marion, N. (1999): Volatility and Investment: Interpreting Evidence from Developing Countries. *Economica* 66: 157 – 79.

Andreoni, J. (1990): Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving? *Economic Journal* 100(401): 464-77

Barrett, S. (1994): Self-Enforcing International Environmental Agreements. *Oxford Economic Papers* 46: 878-894.

Barrett, S. (2006): Climate Treaties and "Breakthrough" Technologies. *American Economic Review* 96(2): 22–25.

Beccherle, J., J. Tirole (2010): Regional Initiatives and the Cost of Delaying Binding Climate Change Agreements. Mimeo.

Branstetter, L.G. (2001): Are knowledge spillovers international or intranational in scope? Microeconometric evidence from the U.S. and Japan. *Journal of International Economics* 53: 53–79

Buchholz, W. and Konrad, K.A. (1994): Global environmental problems and the strategic choice of technology. *Journal of Economics* 60(3): 299-321

Carraro C., D. Siniscalco (1993): Strategies for the International Protection of the Environment. *Journal of Public Economics* 52:309-28.

Chichilnisky, G., G.M. Heal (1994): Who Should Abate Carbon Emissions? An International Perspective. *Economics Letters*, Spring: 443-449.

Coe, D.T., E. Helpman, A.W. Hoffmaister (1997): North-South R & D Spillovers. *The Economic Journal* 107 (440): 134-149.

Edenhofer, O., Carraro, C., Koehler, J., Grubb, M. (eds) (2006): Endogenous Technological Change and the Economics of Atmospheric Stabilisation. A Special Issue of The Energy Journal, Vol. 27, International Association of Energy Economics, USA.

Glazer, A., K.A. Konrad (1996): A Signaling Explanation for Charity. *American Economic Review* 86 (4): 1019-28.

Golombek, R., M. Hoel (2004): Unilateral Emission Reductions and Cross-Country Technology Spillovers. *Advances in Economic Analysis & Policy* 4 (2), Article 3.

Harstad, B. (2009): The Dynamics of Climate Agreements. Mimeo.

Hausmann, R. and Rodrik, D. (2003): Economic development as self-discovery. *Journal of Development Economics* 72(2): 603-633

Heal, G. (1994): Formation of International Environmental Agreements. In Carraro, C. (ed). Trade, Innovation, Environment. Edward Elgar, 301-322.

Heal, G. and Tarui, N. (2010): Investment and emission control under technology and pollution externalities. *Resource and Energy Economics* 32(1): 1-14,

Hof, A.F., den Elzen, M.G.J., van Vuuren, D.P. (2008): Environmental effectiveness and economic consequences of fragmented versus universal regimes: what can we learn from model studies? *International Environmental Agreements: Politics, Law and Economics* 9:39-62

Jaffe, R.N. Newell, R.G. and Stavins, R.N. (2005a): Technological change and the environment. Chapter 11 in Mäler, K.-G., J. Vincent (eds): Handbook of Environmental Economics 3 (1): 461-516. North Holland.

Jaffe, A.B., Newell, R.G. and Stavins, Robert N. (2005b): A tale of two market failures: Technology and environmental policy. *Ecological Economics* 54(2-3): 164-174, Javorcik, B.S. (2004): Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers Through Backward Linkages. *American Economic Review* 94 (3): 605-627.

Junginger, M., A. Faaij, W.C. Turkenburg (2005): Global Experience curves for wind farms. *Energy Policy* 33: 133–150.

Keller, W. (2004): International Technology Diffusion. *Journal of Economic Literature* 42: 752–782.

Kolstad, C. (2007): Systematic uncertainty in self-enforcing international environmental agreements. *Journal of Environmental Economics and Management* 53: 68–79.

Nemet, G.F. (2006): Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34: 3218–3232.

Newell, R.G., Jaffe, A.B. and Stavins, R.N. (2006): The effects of economic and policy incentives on carbon mitigation technologies. *Energy Economics* 28(5-6): 563-578

Nordhaus, W.D. (2009): The Perils of the Learning Curve Model for Modeling Endogenous Technological Change. *NBER Working Paper 14638*

Ostrom, E. (2010): A Multi-Scale Approach to Coping with Climate Change and Other Collective Action Problems. *Solutions* 1 (2): 27-36.

Popp, D. (2006): Innovation in climate policy models: Implementing lessons from the economics of R&D. *Energy Economics* 28 (5-6): 596–609

Samuelson P.A. (1954): The Pure Theory of Public Expenditure. *Review of Economics and Statistics* 36 (4): 387–389

Sinn, H.W. (2008): Das grüne Paradoxon: Plädoyer für eine illusionsfreie Klimapolitik. Econ Verlag. [*english translation 'The Green Paradox' forthcoming at MIT Press*]

Sugden, R. (1984): Reciprocity: The Supply of Public Goods through Voluntary Contributions. *Economic Journal* 94(376): 772-87.

UNFCCC (2011): Draft decision -/CP.17: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention

Urpelainen, J. (in press): Technology investment, bargaining, and international environmental agreements. *International Environmental Agreements: Politics, Law and Economics*.

Vogler, J. and Stephan, H. (2007): The European Union in global environmental governance: Leadership in the making? *International Environmental Agreements: Politics, Law and Economics* 7(4): 389-413,

Appendix

To an increase of public good supplied by private actors, the government reacts with decreasing its contribution to the public good. The total amount of public good can increase or decrease (i.e. it is possible that the government decreases its provision of e by more than the additional provision by h-types. Of course, in a situation like this h-types won't have incentives to supply e in the first place).

Taking total derivates of the government's FOC yields:

$$
\begin{aligned}
& n_h \cdot [\frac{\partial^2 u^h}{\partial c^2} \cdot (\frac{-\theta'(e^g)}{n^h + n^l})^2 de^g + \frac{\partial^2 u^h}{\partial c^2} \cdot (\frac{-\theta'(e^g)}{n^h + n^l}) \cdot (\frac{-\theta'(e^p)}{n^h}) de^p \\
& + 2 \cdot \frac{\partial^2 u^h}{\partial c \partial e} \cdot (\frac{-\theta'(e^g)}{n^h + n^l}) de^g + 2 \cdot \frac{\partial^2 u^h}{\partial c \partial e} \cdot (\frac{-\theta'(e^p)}{n^h}) de^p + \frac{\partial^2 u^h}{\partial e^2} de^g + \frac{\partial^2 u^h}{\partial e^2} de^p] + \\
& n^l \cdot [\frac{\partial^2 u^l}{\partial c^2} \cdot (\frac{-\theta'(e^g)}{n^h + n^l})^2 de^g + 2 \cdot \frac{\partial^2 u^l}{\partial c \partial e} \cdot (\frac{-\theta'(e^g)}{n^h + n^l}) de^g + \frac{\partial^2 u^l}{\partial e^2} de^g + \frac{\partial^2 u^l}{\partial e^2} de^p] = 0
\end{aligned}
$$

This allows us to derive the government's reaction function:

$$
\frac{de^g}{de^p} = - \frac{n_h \cdot [\frac{\partial^2 u^h}{\partial c^2} \cdot \frac{(-\theta'(e^g))}{n^h + n^l} \cdot \frac{(-\theta'(e^p))}{n^h} + 2 \frac{\partial^2 u^h}{\partial c \partial e} \cdot \frac{(-\theta'(e^p))}{n^h} + \frac{\partial^2 u^h}{\partial e^2}] + n_l \cdot [\frac{\partial^2 u^l}{\partial e^2}]}{n_h \cdot [\frac{\partial^2 u^h}{\partial c^2} \cdot \frac{(-\theta'(e^g))^2}{n^h + n^l} + 2 \frac{\partial^2 u^h}{\partial c \partial e} \cdot \frac{(-\theta'(e^p))}{n^h} + \frac{\partial^2 u^h}{\partial e^2}] + n_l \cdot [\frac{\partial^2 u^l}{\partial c^2} \cdot \frac{(-\theta'(e^g))^2}{n^h + n^l} + 2 \frac{\partial^2 u^l}{\partial c \partial e} \frac{(-\theta'(e^g))}{n^h + n^l} + \frac{\partial^2 u^l}{\partial e^2}]}
$$

Checking signs, it is obvious that the reaction term is always negative. This proves the first part of the proposition. Inspecting terms reveals that the absolute value can be greater or smaller than one. It is smaller (i.e. the government's reaction function is flatter, it will decrease its provision of e by less) (1) the larger the share of h-types in the population, and (2) the smaller $\frac{\partial^2 u^l}{\partial c^2}$ and $\frac{\partial^2 u^h}{\partial c^2}$ (i.e. the less additional utility h- and l-types derive from paying lower taxation due to less public good to be provided by the government).

Figures

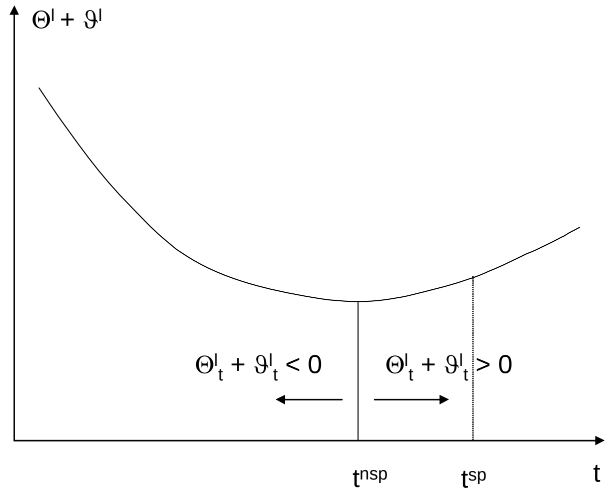

Figure 1: With a convex cost function, the level of technology *t* provided by the leader will be higher with technology spillovers (t^{sp}) than without spillovers (t^{nsp})