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Abstract

We analyze a situation where a principal wants to induce two firms to produce an output, e.g. electricity from renewable energy sources. Firms can undertake non-contractible investments to reduce production cost of the output. Part of these investments spills over and also reduces production cost of the other firm. Comparing a general price subsidy and an innovation tournament, we find that the principal's expected cost of implementing a given expected output are always higher under the tournament, even though this scheme may lead to more innovation.

JEL Classification: Q55; D82; H23; D43

Keywords: R&D spillovers; tournaments; subsidies; moral hazard

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1 Introduction

In this paper we analyze a situation where a principal wants to induce two firms to produce an output. The firms can undertake a costly investment to reduce production cost of the output. Part of this 'innovation' spills over and also reduces production cost of the other firm. We focus on the principal's choice between subsidizing all firms or only the most successful innovators.

A topical problem that conforms to this general structure are recent measures to increase electricity production from renewable energy sources in order to combat climate change and to reduce dependency on fossil energy. Renewable energy is not competitive yet, but the hope is that innovations will bring down production costs (Manne and Richels 2004). Therefore, several countries like Germany, France and Spain have passed legislation by which all producers of renewable energy receive a fixed price for power sold to the grid that lies above the market price. The instrument went quite well in practice. For example, the share of renewables in the consumption of electricity increased in Germany from 4.6% in 1998 to 9.3% in 2004 (BMU 2005).

Nevertheless, some decision-makers have suggested that the subsidies should be focused on the most promising projects only.[1] Therefore, we compare the general price subsidy to an innovation tournament, where only the winner receives an output price subsidy. This has an additional advantage. Firms disregard the beneficial effect that innovation spillovers have on other firms, resulting in underinvestment. A tournament may strengthen innovation incentives since the firms try to outperform each other.

An innovation tournament has substantial similarities with the Non-Fossil Fuel Obligation (NFFO) in the UK (Cleirigh 2001). Under this scheme renewable energy production projects were awarded to the firm who asked the lowest price for producing a specified output. Intuitively, the firm which realized the better cost-reducing innovation should win the bidding competition. This is also the case in our tournament model, which is more simple, however, since it

[1] See the debate between the then German ministers for the economy and the environment ('Clement sucht Konfrontation mit Trittin', Frankfurter Allgemeine Zeitung, 02.09.2003, p. 11). Also the new German chancellor Angela Merkel has criticized that "everyone has access to the subsidies" ('Schwarz-gelber Mix', DIE ZEIT, 02.06.2005, p. 24).

disregards the strategic interaction at the bidding stage. In practice, the NFFO had only limited success, and it has been replaced recently by a quota system.

We model firms' choices as a two stage game. In the first stage, firms invest into an innovation that reduces the cost of producing output. In the second stage, stochastic innovations are observed and production takes place. While we assume that output can be contracted upon, contracts based on the value of innovation are not feasible. The reason is that even if the principal (i.e. the government) and the firms can evaluate the innovation, such information is usually difficult to verify by a court. Moreover, we assume that firms' investments are not observable. Therefore, we have a moral hazard problem and the first best innovation/output profile will not be implementable if firms are wealth constrained.

The government wants to minimize the expected costs of achieving an output target, e.g. regarding electricity from renewable energies. We focus on two policy instruments: a general output price subsidy (GPS), and an innovation tournament such that only the winner receives an output price subsidy. This restriction to subsidize either both firms to the same extent or only one firm keeps the analysis tractable. Furthermore, these two schemes seem to be the most relevant, since guaranteeing firms different prices for electricity that has been generated from the same renewable energies would probably constitute illegal price discrimination.

A central feature of our model is that innovation is not completely appropriable due to technological spillovers, which may be substantial even in the presence of patent protection (Mansfield 1985). Reasons are (*i*) personnel movements between employers, (*ii*) formal and informal networks between researchers such as seminars, publications and casual encounters, as well as (*iii*) reverse engineering (see Geroski 1995). The first two channels relate to (input) spillovers that occur during the R&D process. The third channel relates to spillovers of the final R&D output. The formal analysis in our paper is restricted to the former. However, in the concluding remarks we will argue that spillovers of R&D output further strengthen our main result.

The analysis focuses on two related issues: innovation investments and the government's cost of implementing a targeted output level. Investments may be higher under the tournament than under the GPS if the stakes are such that firms are highly motivated to win the innovation contest. However, research spillovers dilute this motivation since they reduce the effect of own research efforts on the chances of winning. Furthermore, a firms ex-ante expected output is higher under the GPS, which increases the incentive to invest in cost reducing innovations under this scheme. In summary, it turns out that with perfect spillovers the GPS always induces more innovation investments, while the comparison is ambiguous if spillovers are low.

However, even in those cases where the tournament induces more innovation, it always leads to higher expected costs of implementing a targeted output level. One reason is that we assume diminishing returns to scale of output production, which favors the GPS where both firms produce. Our model allows this effect to be arbitrarily small, but in this case the GPS turns out to produce the better innovation.

Our basic setup is related to the large industrial organization literature on innovation spillovers. A seminal contribution of this literature is d'Aspremont and Jacquemin (1988), who also consider the interaction among firms that invest in cost-reducing innovations. These are not completely appropriable due to spillovers, leading to underinvestment in R&D.[2]

Our paper differs from d'Aspremont and Jacquemin (1988) and most of the related literature in several important respects. First, there is no problem of imperfect competition in our framework. This seems realistic since the market share of renewable energies is small so that individual producers have no influence on the electricity price.

Second, we assume that innovation is stochastic and the related investment non-contractible. Other papers that analyze stochastic innovation are Martin (2002) and Gehrig (2004). In Martin (2002) uncertainty is modeled as an uncertain discovery time. Essentially, he analyzes a patent racing model of cost-saving innovation in a quantity-setting duopoly. In Gehrig (2004) the development of an idea succeeds with a certain probability, and the firm invests

[2]Related papers are Suzumura (1992) who provides a generalization of d'Aspremont and Jacquemin (1988), as well as Kamien, Muller, and Zang (1992) who consider spillovers of research inputs (rather than research outputs). For surveys of the literature on knowledge spillovers in an imperfectly competitive market environment see DeBondt (1997) and Amir (2000).

resources to find out the likely success of the innovation. In our paper, investments improve the distribution of the stochastic innovation and, thereby, reduce expected production cost.

Third, there is an active regulator who can use his budget to provide incentives for innovation investments and output production. Hinloopen (1997) also considers an active government, but he focuses on R&D subsidies, which are non-contractible in our framework. There is also a substantial environmental economics literature on the stimulation of technological innovation. However, most of this literature analyzes firms' decisions to adopt a known technology under different instruments such as permits, taxes and standards (e.g., Requate and Unold 2003; Jung, Krutilla, and Boyd 1996).

Nevertheless, some notable exceptions exist. Fisher, Parry, and Pizer (2003) analyze endogenous innovation and also allow for research spillovers. However, in their model only one firm is an innovator, the innovation process is deterministic and they analyze different policy instruments than we do, namely taxes and permits. Biglaiser and Horowitz (1995) considers binary choices whether to undertake research into a technology that reduces the emission intensity of production. In Tsur and Zemel (2002), a regulator auctions the procurement of an environmental project to an individual firm, and conditions transfers to this firm on the project completion time.

The paper proceeds as follows. Section 2 introduces the model. Sections 3 and 4 analyze the GPS and the tournament, respectively. Section 5 compares these two policy instruments, and section 6 concludes.

2 The model

There are two ex-ante identical firms indexed alternatively by $i, j = 1, 2$. In the first stage, the government commits to a mechanism, i.e. either a general price subsidy (GPS) or a tournament. In the second stage, each firm undertakes a non-observable investment, $x_i \geq 0$, into the development of a process innovation that reduces production cost. The uncertain and non-verifiable innovation output of this investment is e_i, where $e_i \in [0, 1]$ is the realization of a random variable with cumulative distribution function $F_i(e_i|x_i, x_j) = e_i^{g_i(x_i,x_j)}$, and density function $f_i(e_i|x_i, x_j) = g_i(x_i, x_j)e_i^{g_i(x_i,x_j)-1}$. Given x_i and x_j, the two random variables are independently distributed.

The function $g_i(x_i, x_j) \geq 0$ is assumed to be strictly increasing and concave in x_i and twice partially differentiable in x_i and x_j. That is, a higher investment of firm i improves the distribution of its innovation in the sense of first order stochastic dominance and, therefore, reduces expected production costs.[3] Furthermore, $g_i(x_i, x_j)$ may also increase in x_j, which means that there are spillovers of R&D inputs. However, a firm's own investments have a (weakly) more beneficial effect on the distribution of its innovation than foreign investments. This reflects that spillovers are usually incomplete and that knowledge acquired from rivals may not fit exactly with a firm's existing knowledge base (see Hinloopen 2003). Formally, we assume that

$$\frac{\partial g_i(x_i, x_j)}{\partial x_i} > 0, \ \frac{\partial g_i(x_i, x_j)}{\partial x_j} \geq 0, \ \frac{\partial^2 g_i(x_i, x_j)}{\partial x_i^2} \leq 0 \qquad i, j = 1, 2, \ i \neq j, \qquad (1)$$

and

$$\forall x, y \geq 0, \ \left.\frac{\partial g_i(x_i, x_j)}{\partial x_i}\right|_{x_i = x, x_j = y} \geq \left.\frac{\partial g_j(x_i, x_j)}{\partial x_i}\right|_{x_i = x, x_j = y} \qquad i, j = 1, 2, \ i \neq j. \qquad (2)$$

Furthermore, since firms are identical ex ante, $g_i(x, y) = g_j(y, x)$ for all $x, y \geq 0$.

In the third stage, each firm observes its innovation and produces the verifiable output $q_i, q_j \geq 0$. Firm i's total production cost after accounting for the process innovation are given by

$$c(x_i, e_i, q_i) = \frac{q_i^{1+s}}{(1+s)e_i^t} + x_i, \qquad s, t > 0. \qquad (3)$$

Accordingly, cost of output is increasing and convex, reflecting diminishing returns to output production. Production cost decrease in the innovation output e_i. The parameters s and t describe how responsive production costs are to changes in q_i and e_i, respectively. In particular, $1 + s$ is the elasticity of production cost with respect to output q_i, and $-t$ is the elasticity of production cost with respect to the innovation level e_i. Note that the model focuses on

[3] For example, if $F(e_i) = e_i^{a x_i}, a > 0$, firm i takes x_i identical, independent draws from the distribution $F(e_i) = e_i^a$. See Fullerton and McAfee (1999) for a similar specification of random innovations.

innovation which is ‘essential’ in the sense that production cost rise to infinity in the absence of innovation.

All parties are risk neutral and firms’ reservation utility is zero. Furthermore, firms are wealth constrained so that they cannot pay entry fees for participation in the tournament or for being entitled to receive subsidies. For parsimony, we assume that firms receive payments for their output and innovation only from the principal. Accordingly, under the tournament scheme the losing firm which receives no subsidy will not produce output. This reflects that renewable energy production is not competitive yet.

It remains to specify the government’s objective function. We assume that it wants to minimize its expected costs for implementing a given expected overall output $\bar{q} > 0$. In our opinion, this better reflects actual decision processes than a maximization of social welfare. Especially since the monetarized benefits of producing electricity from renewable rather than ‘conventional’ energy are essentially not known. It also emphasizes our focus on problems where the government is not interested in innovation per se, but in an output that can be produced more cheaply if innovation occurs. Furthermore, none of our main results depends on the targeted output level $\bar{q}$.

3 General price subsidy

The game is solved by backwards induction, and we first consider the GPS. In the last stage, given innovation e_i, firm i chooses output q_i to maximize earnings less production cost:

$$\max_{q_i} \; pq_i - \frac{q_i^{1+s}}{(1+s)e_i^t}. \tag{4}$$

From the first order condition, output is chosen according to

$$q_i(p, e_i) = \left(pe_i^t\right)^{1/s}. \tag{5}$$

In the investment stage, anticipating $q_i(\cdot)$ and given firm j’s investment x_j, firm i solves

$$\max_{x_i} \; E\left[p\left(pe_i^t\right)^{1/s} - \frac{\left(pe_i^t\right)^{\frac{1+s}{s}}}{(1+s)e_i^t}\right] - x_i \;=\; \max_{x_i} \; \frac{p^\sigma}{\sigma}E[e_i^\nu | x_i, x_j] - x_i, \tag{6}$$

where $\sigma := (1+s)/s$, $\nu := t/s$, and

$$E[e_i^\nu|x_i,x_j] = \int_0^1 e_i^\nu g_i(x_i,x_j) e_i^{g_i(x_i,x_j)-1} de_i \tag{7}$$
$$= \frac{g_i(x_i,x_j)}{g_i(x_i,x_j)+\nu}. \tag{8}$$

Asymmetric equilibria may exist. However, since firms are identical ex ante, we concentrate on a symmetric equilibrium $x_i = x_j =: x_a$ in the investment stage. Assuming that p is large enough to induce positive investments, it follows from the first order condition that, under the GPS, a firm's investment x_a is given by[4]

$$\frac{p^\sigma}{\sigma} \frac{\nu \left.\frac{\partial g_i}{\partial x_i}\right|_{x_a}}{(g_a+\nu)^2} - 1 = 0, \tag{9}$$

where $g_a := g_i(x_a, x_a)$.[5] Implicit differentiation shows that investments under the GPS increase in the output price. Intuitively, for any given innovation e_i a higher price induces more output (see 5). This makes cost reducing investments more beneficial.

Using (5) and (8), expected overall output is

$$q_a(p) := E[q_i + q_j|x_a] = 2p^{\frac{1}{s}} E[e_i^\nu|x_a] = 2p^{\frac{1}{s}} \frac{g_a}{g_a+\nu}. \tag{10}$$

The effect of spillovers on investments and output depends on the characteristics of the function $g_i(x_i,x_j)$. For example, suppose that $g_i(x_i,x_j) = x_i + zx_j$, $0 \leq z \leq 1$. Implicit differentiation of (9) then shows that

$$\frac{dx_a}{dz} = -\frac{x_a}{1+z}, \tag{11}$$

i.e. investments under the GPS decrease in input spillovers. Intuitively, given that own and foreign investments are substitutes, a firm's incentive to invest decreases as it can absorb more of the other firm's innovation investments. However, this need not be the case if investments are complements, i.e. if the

[4]The second order condition holds since (6) is concave in x_i.

[5]Participation constraints hold under both mechanisms since investing $x_i = 0$ leads to an expected payoff of at least zero, so that the expected payoff under the optimal investment must be nonnegative.

effect of own investments on g_i increases as R&D spillovers from the other firm increase.

From (10), expected output is increasing in g_a. Denoting R&D spillovers by $z_i(x_i, x_j) := \frac{\partial g_i(x_i,x_j)}{\partial x_j}$ we obtain

$$\frac{d}{dz_i} g_i\left(x_a(z_i), x_a(z_i); z_i\right) = \frac{\partial g_i}{\partial x_i}\frac{dx_i}{dz_i} + \frac{\partial g_i}{\partial z_i}. \tag{12}$$

While the second term is positive, we have just argued that the first term may be negative if investments are substitutes. This is the case for the example $g_i = x_i + zx_j$, for which the two effects just cancel out so that expected output is independent of R&D spillovers.

4 Tournament

Under the GPS firms disregard the positive effect that R&D spillovers have on the production cost of other firms. In order to stimulate innovation investments, the government may consider research tournaments. Under this scheme only the winner, i.e. the firm with the better innovation, receives the price subsidy.[6] Accordingly, firms have an additional investment incentive since they want to outperform each other.

The sequence of moves is the same as in the previous section: In stage 1, the government commits to a price subsidy for the tournament winner. In stage 2, firms invest and the winner is determined. Ties are solved by flipping a fair coin. Since they occur with probability zero, they are henceforth neglected. In stage 3, the winner produces output. By assumption, the losing firm will not find it profitable to produce.

Without loss of generality assume that firm i realizes the better innvoation, i.e. $e_i > e_j$. In the last stage, its problem of maximizing profits for a given innovation is equivalent to the GPS, leading to output $q_i(p, e_i)$ as given in (5).

Turning to the investment stage, the expected e_i^ν of the tournament winner

[6] This requires that realized innovations are observable by the government, but they need not be verifiable to a third party.

is

$$
\begin{aligned}
E\left[\max\{e_i^\nu, e_j^\nu\}|x_i, x_j\right] &= 2\int_0^1 \int_0^{e_i} e_i^\nu f_j(e_j|x_i,x_j) f_i(e_i|x_i,x_j) de_j de_i & (13)\\
&= 2\int_0^1 e_i^\nu e_i^{g_j(x_i,x_j)} g_i(x_i,x_j) e_i^{g_i(x_i,x_j)-1} de_i & (14)\\
&= \frac{2g_i(x_i,x_j)}{g_i(x_i,x_j)+g_j(x_i,x_j)+\nu}. & (15)
\end{aligned}
$$

Comparing (8) and (15), for given investments $x_i = x_j$ the expected innovation level of the tournament winner is larger than the average innovation level under the GPS. This reflects that the tournament selects the most successful innovator. However, the chance of winning is only 50 percent. Hence for a given price p and investments $x_i = x_j$, each firm's ex-ante expected output is lower under the tournament than under the GPS, i.e. $\frac{1}{2} p^{\frac{1}{s}} E[\max\{e_i^\nu, e_j^\nu\}] < p^{\frac{1}{s}} E[e_i^\nu]$.

In particular, anticipating $q_i(p, e_i)$ firm i chooses investments to solve

$$
\max_{x_i} \frac{p^\sigma}{2\sigma} E\left[\max\{e_i^\nu, e_j^\nu\}|x_i, x_j\right] - x_i. \tag{16}
$$

Again, we restrict attention to a symmetric equilibrium, which we denote by $x_i = x_j =: x_t$, and assume an interior solution. From the first order condition, x_t is given by

$$
\frac{p^\sigma}{\sigma} \frac{\frac{\partial g_i}{\partial x_i}\Big|_{x_t} (g_t+\nu) - g_t \frac{\partial g_j}{\partial x_i}\Big|_{x_t}}{(2g_t+\nu)^2} - 1 = 0, \tag{17}
$$

where $g_t := g_i(x_t, x_t) = g_j(x_t, x_t)$. We assume that firm i's objective function (16) is concave for every x_j so that the second order condition holds.[7]

From (5) and (15), expected output under the tournament is

$$
q_t(p) := p^{1/s} E\left[\max\{e_i^\nu, e_j^\nu\}|x_t\right] p^{1/s} \frac{2g_t}{2g_t+\nu}. \tag{18}
$$

To analyze the effect of spillovers on innovation investments, consider again the example $g_i(x_i, x_j) = x_i + zx_j$, $0 \le z \le 1$. Implicit differentiation of (17) then yields

$$
\frac{dx_t}{dz} = \frac{2zx_t[2(1+z)x_t+\nu] + 4x_t[(1-z^2)x_t+\nu]}{(1-z^2)[2(1+z)x_t+\nu] - 4(1+z)[(1-z^2)x_t+\nu]} < -\frac{x_t}{1+z}, \tag{19}
$$

[7] This is case if, e.g., $g_i(x_i, x_j) = x_i + zx_j$, $0 \le z \le 1$.

since the denominator is negative by the second order condition. Comparing this with (11), R&D spillovers have a more detrimental effect on investments under the tournament than under the GPS. Intuitively, the higher spillovers, the lower the effect that own investments have on the chances of winning the tournament.

We now turn to a more thorough comparison of investments and of the government's cost of implementing a targeted output level under the two schemes.

5 Comparison of the two schemes

In the previous section we have discussed three effects that determine differences in innovation investments under the GPS and the tournament. First, for a given price p and identical investments x_i, x_j, each firm's ex-ante expected output is lower under the tournament. This weakens incentives to invest in cost reducing innovations under this scheme. Second, the tournament rewards the firm that achieves the best innovation. This strengthens incentives to invest. Third, the latter effect is diluted through spillovers of research inputs. If they are perfect, own investments have no effect on the chances of winning the tournament anymore.

The comparison of the expected innovation level under the two schemes depends on the relative strength of these effects. With perfect spillovers the GPS always induces more innovation. As spillovers are reduced, the comparison becomes ambiguous and it may happen that the tournament performs better. In particular, with no spillovers the tournament leads to more innovation if the expected e_i^ν – and therefore the expected payoff – of the tournament winner is large, since this implies a high incentive to win the tournament. Noting that $E\left[\max\{e_i^\nu, e_j^\nu\}|x_i, x_j\right]$ increases in g_i and falls in $\nu = \frac{t}{s}$, the following proposition summarizes these considerations.

Proposition 1 *For any given output price p that induces positive investments, with perfect input spillovers $x_a > x_t$. With no input spillovers, $x_t > x_a$ if and only if $sg_a > 0.5t(1 + \sqrt{5})$.*

Proof. Given p, from (9) and (17), $x_a > x_t$ if and only if

$$\frac{\sigma}{p^\sigma} = \frac{\nu \left.\frac{\partial g_i}{\partial x_i}\right|_{x_a}}{(g_a+\nu)^2} \geq \frac{\left.\frac{\partial g_i}{\partial x_i}\right|_{x_a}(g_a+\nu) - g_a \left.\frac{\partial g_j}{\partial x_i}\right|_{x_a}}{(2g_a+\nu)^2}, \tag{20}$$

where the r.h.s. has been obtained from evaluating (17) at $x_t = x_a$. With perfect spillovers, $\frac{\partial g_i}{\partial x_i} = \frac{\partial g_j}{\partial x_i}$, the numerators are the same on both sides of the inequality sign, and the first statement follows straightforwardly. With no input spillovers, (20) simplifies to

$$\frac{\nu}{(g_a+\nu)^2} \geq \frac{g_a+\nu}{(2g_a+\nu)^2}. \tag{21}$$

Given that $x_a > 0$ and thus $g_a > 0$, the above inequality holds if and only if $g_a \leq \frac{\nu}{2}(1+\sqrt{5})$. □

Obviously, investments under the two schemes are crucial for the government's cost of implementing a targeted output level. According to Proposition 1, this will favor the GPS more often. In addition, given our assumption of convex production cost the GPS has the advantage that both firms produce output, although this effect is small as s approaches 0. On the other hand, the tournament enables the government to concentrate subsidies on the firm that has been most successful in reducing its production costs. As the following results show, it turns out that the effects which favor the GPS always dominate.

Proposition 2 *The government's expected cost of implementing a given expected output $\bar{q} > 0$ are always lower under the GPS than under the tournament scheme.*

Proof. The proof is by contradiction. Assume that the government's expected costs for implementing a given expected output $\bar{q}$ are lower under the tournament, i.e.

$$p_t(\bar{q})\bar{q} < p_a(\bar{q})\bar{q} \qquad \Leftrightarrow \qquad q_t(\bar{p}_t) > q_a(\bar{p}_t), \tag{22}$$

where $\bar{p}_t := p_t(\bar{q})$ is the price required to implement quantity $\bar{q}$ under the tournament. By (10) and (18), this is the case if and only if at $\bar{p}_t$

$$2E[e_i^\nu | x_i = x_j = x_a] \leq E[\max\{e_i^\nu, e_j^\nu\} | x_i = x_j = x_t] \tag{23}$$

$$\Leftrightarrow \quad \frac{g_a}{g_a+\nu} \leq \frac{g_t}{2g_t+\nu} \tag{24}$$

$$\Leftrightarrow \quad g_a \leq \frac{\nu g_t}{g_t+\nu}. \tag{25}$$

A necessary condition for this inequality to hold is $g_a \leq g_t$ or, equivalently, $x_a \leq x_t$. From Proposition 1 and the associated proof we know that this requires $g_a \geq \frac{\nu}{2}(1+\sqrt{5})$. However, this is in contradiction to inequality (25) which can hold only if $g_a < \nu$. □

For the tournament to be better than the GPS, there must be a price p such that $q_t > q_a$. That is, the winner of the tournament must produce at least twice as much output as each firm under the GPS. This would requires that the production cost function is not too convex (i.e. s is low), and that the tournament winner's expected innovation is substantially higher than the average innovation under the GPS (see 23). However, whenever investment incentives are higher under the tournament, they are also relatively high under the GPS. Furthermore, whenever s is low the GPS leads to the better innovation (see Proposition 1). Therefore, expected output under the GPS is always higher.

6 Concluding Remarks

We have motivated our analysis by the problem of promoting new technologies such as renewable energies. While not being competitive yet, energy production from renewables is characterized by steep learning curves. This has been captured by assuming that production cost can be reduced by non-contractible investments into innovations, which partly spill over to other firms. These spillovers, together with our assumption of diminishing returns to scale, provide a strong rationale for inducing production from both firms in our model.

However, with non-contractible innovation investments firms disregard the beneficial effect that R&D spillovers have on other firms. Therefore, we have considered the alternative instrument of a research tournament, which provides additional investment incentives since firms try to outperform each other. Furthermore, under the tournament subsidies are targeted at the most successful innovator. Nevertheless, we find that the government's expected cost of inducing a targeted output level are always lower under the GPS. Furthermore, in many cases the GPS also induces more innovation.

Therefore, the paper provides strong support for the system of guaranteeing a fixed output price for renewables, which has been applied rather successfully in several EU countries. This conclusion seems to be further strengthened if we allow for output spillovers, which occur if firms learn from each other during the production process, e.g. through reverse engineering. Accordingly, they would lower production costs only under the GPS, where both firms produce.

Another issue which has not been considered is that firms can take measures to prevent spillovers. Since spillovers tend to be more detrimental under the tournament, firms are more likely to do so under this scheme. Noting that spillovers are beneficial from a social point of view, this would further strengthen the case for the GPS.

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