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Hold-up Problems with Respect to R&D Investment and Licensing in Environmental Regulation

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Non-Technical Summary

Self-financing tax-subsidy schemes can be a powerful policy tool to spur welfare-enhancing investments and licensing in oligopolies. Consider environmental regulation settings, where any firms` investments in the development of non-polluting technologies are costly and where one firm can become a licensee of the non-polluting technology if another firm has developed it. Firms may behave strategically by investing little or refusing to apply for a license to save costs while hoping to force the regulator to adopt looser regulations, which is denoted as hold-up problem. Self-financing tax-subsidy schemes treat firms alike, whether they invest enough/ become a licensee or not.

We analyze hold-up problems with respect to the investment in environmental R&D as well as hold-up problems with respect to the licensing of environmentally friendly technologies. We investigate two different self-financing tax-subsidy mechanisms (announcing the tax rate versus announcing the subsidy rate) and analyze whether they can overcome existent hold-up problems. In addition, we compare the social welfare implications of these two alternative tax-subsidy mechanisms and of the standard emission taxation.

The announcement of the tax rate seems to be preferable to solve hold-up problems with respect to the investment in environmental R&D. In contrast, only the announcement of the subsidy rate is adequate to solve hold-up problems with respect to the licensing of environmentally friendly technologies. Altogether, the announcement of the subsidy rate yields higher expected social welfare than the announcement of the tax rate or the standard emission taxation if the marginal damage of emissions exceeds a certain level.

Hold-up Problems with Respect to R&D Investment and Licensing in Environmental Regulation*

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Abstract

We explore the design of self-financing tax-subsidy schemes to solve hold-up problems in environmental regulation. The announcement of the tax rate seems to be preferable to solve hold-up problems with respect to the investment in environmental R&D. In contrast, only the announcement of the subsidy rate is adequate to solve hold-up problems with respect to the licensing of environmentally friendly technologies. Altogether, the announcement of the subsidy rate yields higher expected social welfare than the announcement of the tax rate or the standard emission taxation if the marginal damage of emissions exceeds a certain level.

Keywords: Hold-up problems; Environmental regulation; Taxes and subsidies; Self-financing mechanisms; Emission control

JEL classification: D43, D62, L50, Q28

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1 Introduction

Self-financing tax-subsidy schemes can be a powerful policy tool to spur welfare-enhancing investments and licensing in oligopolies. Consider environmental regulation settings, where any firms‘ investments in the development of non-polluting technologies are costly and where one firm can become a licensee of the non-polluting technology if another firm has developed it. Firms may behave strategically by investing little or refusing to apply for a licence to save costs while hoping to force the regulator to adopt looser regulations, which is denoted as hold-up problem. Self-financing tax-subsidy schemes treat firms alike, whether they invest enough / become a licensee or not. If one firm produces with a non-polluting technology and the other causes emissions, the polluting firm must pay taxes, which are used in turn to subsidize the environmentally friendly firm. The regulator can credibly trigger investments in the development of environmentally friendly technologies and licensing of the environmentally friendly technology.

Hold-up problems are real-world phenomena. For instance, the standards specified by the 1970 American Clean Air Act were repeatedly delayed. Most dramatically, faced with industry claims that the proposed emission standards would shut down factories, Congress amended the Act in 1977, thus both weakening and postponing the standards. Similarly, in 1988 the government delayed standards for the 1989 model year. Further evidence of the hold-up problem can be found in Weimann (1995), where the "cartel of silence" on the part of engineers is illustrated as preventing the government from imposing tighter regulations.

Another recent example illustrates credibility problems. In 1998, Congress included a provision in the highway bill that delayed the first steps towards bringing states into compliance with the Clean Air Act's long-standing goal of "reasonable progress" toward eliminating man-made haze in specially protected areas for six to nine years. Until Congress intervened, the Environmental Protection Agency had planned to ask states to file preliminary plans by 1999, showing how they would eventually raise visibility standards gradually over the next few decades by complying with the new rules that had been proposed two years earlier.[1]

We analyze hold-up problems in the context of environmental R&D investments as well as the licensing of environmentally friendly technologies and evaluate whether self-financing mechanisms can overcome existent hold-up problems. In addition, we compare the social welfare implications of two alternative tax-subsidy mechanisms and of the standard emission taxation.

Our scheme might be applied as a "feebate"-system in the automotive sector to promote the sale of environmentally friendly cars. Feebates generally refer to fees on fuel-inefficient vehicles and rebates on fuel-efficient ones. A first option of a feebate-system is taxation of the purchase of cars which exceed a certain emission level, and to refund the tax revenues to the buyers of cleaner cars. A second option is the implementation of a feebate-system at the industry level, which would be equivalent to our tax-subsidy scheme. The production of environmentally friendly cars could be subsidized by using the revenues from the taxation of the production of environmentally harmful cars.

2 Relation to the Literature

Our paper relates to different strands of the literature. Gersbach (2002) has suggested self-financing tax-subsidy mechanisms as a solution for hold-up problems by announcing subsidies when firms compete à la Cournot. Breitscheidel and Gersbach (2003) have analyzed whether the regulator should set taxes or subsidies when using tax-subsidy mechanisms.

More basically, our paper draws from the literature on the original hold-up problem, where a firm facing a single buyer may find investment unprofitable if, after making the investment, the buyer offers to pay only marginal costs. This problem has been discussed

[1] See New York Times, May 27, 1998.

in Klein, Crawford and Alchian (1978), Joskow (1987), Williamson (1983), and in the incomplete-contract literature (see the survey by Hart (1995)).

The idea that governmental threats or promises may not be credible has already been discussed in literature on trade protection (Staiger and Tabellini (1987), Matsuyama (1990), Tornell (1991)), regulation of utilities (Salant and Woroch (1992)), Gilbert and Newbery (1994), Urbiztondo (1994)), and privatization (Levy and Spiller (1997)). It is therefore generally being assessed that the hold-up problem is only solvable if there are means which make governmental regulation credible. Therefore in our paper, we analyze the investment and licensing incentives of two alternative self-financing tax-subsidy schemes as compared to the incentives of standard emission taxation.

Furthermore, our analysis involves the concepts of mechanism design that uses the tools of multi-stage games and subgame perfect equilibria (see Varian (1994) or Moore (1992) for a review of the literature). Addressed from this perspective, tax-subsidy mechanisms are examples of subgame perfect implementation of environmental regulation.

Our paper refers to work about the incentives to adopt clean technologies in the design of environmental policy instruments. Milliman and Prince (1989) and Jung, Krutilla and Boyd (1996) examine firms' incentives to invest in new technology, and provide a ranking of different policy instruments (see also Laffont and Tirole (1996), Requate (1995) and Requate and Unold (2003)). In our context, we examine incentives to invest in clean technologies when a firm can influence the tightness of regulation by its investment decision.

Since we are considering R&D-processes, there is a connection to the literature about the incentives of environmental regulation to innovate in clean technologies (Innes and Bial (2002), Porter and van der Linde (1995). Strategic firm behavior plays also an important role in this context (Yao (1988), Malik (1991), Biglaiser, Horrowitz and Quiggin (1995)). Finally, our paper is related to the licensing literature (Gallini (1984), Katz and Shapiro (1989)).

3 Model

We consider an industry with two firms denoted by $i = 1, 2$ producing a homogenous good. The firms compete á la Cournot and the marginal cost of production is zero and is independent of the installation of abatement technology.

$$Q = q_1 + q_2 \tag{1}$$

is the industry's output, where q_i denotes the output of firm i. Social welfare depends on consumer surplus $S(Q)$, on producer surplus net of investment costs $P(Q)$, on investment outlays of each Firm I_i ($I_i \in R_0^+$) and on the social costs of emissions $D(E)$, whereby E denotes the amount of emissions. $D(E)$ is the social damage in terms of willingness to pay and is set to fulfill the following conditions:

$$\frac{\partial D(E)}{\partial E} > 0, \ \frac{\partial^2 D(E)}{\partial E^2} \geq 0, \quad D(0) = 0. \tag{2}$$

Therefore, social welfare, denoted by W, is given by

$$W = S(Q) + P(Q) - I_1 - I_2 - D(E). \tag{3}$$

The inverse demand function is linear and the product price $p \geq 0$ is

$$p = 1 - bQ, \tag{4}$$

with $b > 0$.

Without investing in R&D, no emission abatement technology is available to the firms. But the firms can invest in the development of a perfect abatement technology, whereby this technology has the same properties as the conventional technology except for the fact that it operates free of emissions. The demand is independent of the technology as well. Ulph and Ulph (1996) denote this R&D process as environmental R&D. A firm develops the environmentally friendly technology with the probability $\Theta(I_i)$, whereat both firms research independently of each other and it is possible that both firms develop the new technology.[2] Θ is a continuous function and has the following properties

$$\Theta(0) = 0, \quad \lim_{I_i \to \infty} \Theta(I_i) < 1, \quad \frac{\partial \Theta(I_i)}{\partial I_i} > 0, \quad \lim_{I_i \to 0} \frac{\partial \Theta(I_i)}{\partial I_i} = \infty, \quad \frac{\partial^2 \Theta(I_i)}{\partial I_i^2} < 0 \tag{5}$$

If only one firm (say firm i) has developed the new technology, it can offer that technology to the other firm at an arbitrary price of licensing V_i. If the other firm accepts this offer, both firms can use the development without additional costs. The chronology of regulation and firm decisions is as follows:

Stage 1: Announcement of regulatory framework and subsidy/tax rates		
Stage 2: R&D: Investment and realization of R&D achievement		
Stage 3:	Fixing of V_i and purchase decision of firm j $(i, j \in \{1, 2\},\ i \neq j)$	if only firm i has developed the new technology
	no activities	else
Stage 4: Implementation of regulation (subsidy/tax rates)		
Stage 5: Production and competition		

We only consider symmetric equilibria with respect to the investment decision at the second stage (since both firms are identical) and write $I = I_1 = I_2$.

4 Emission Taxation, Tax-Subsidy Schemes, and Hold-up Problems

4.1 Emission Taxation

As a starting point of regulation, we consider the standard emission taxation, denoted by tax-REG, whereat the tax revenues are passed on to the consumers via a lump-sum-transfer.

[2]See Katsoulacos und Xepapadeas (1996).

Under tax-REG, the regulator maximizes W, taking the investment and licence decisions of the firms as given.

4.2 Hold-up Problems

Two different kinds of hold-up problems can occur. The first one is the one with respect to the firmsb4 investment levels. We define:

Definition 1 *The hold-up problem with respect to investment (*$\boldsymbol{HUP^I}$*) exists, if and only if firms invest ceteris paribus less than would be welfare maximizing.*

The second hold-up problem is the one with respect to the licensing decisions. It is desired from a welfare point of view that the firm, which did not derive an environmentally friendly technology from the R&D measures, purchases the non-polluting technology from the other firm, if only the other firm did develop the environmentally friendly technology in the R&D process. Additionally, it is simple to show that the unsuccessful firm will purchase the new technology if and only if $t^K \leq \frac{2}{5}$, where t^K denotes the tax rate per unit of product sold for the polluting firm under tax-REG if the other firm produces without emissions. This yields the second definition:

Definition 2 *The hold-up problem with respect to licensing (*$\boldsymbol{HUP^L}$*) exists if and only if* $t^K > \frac{2}{5}$.

4.3 Tax-Subsidy Scheme

As an alternative to tax-REG we consider a self-financing tax-subsidy scheme. Our self-financing constraint ensures that no funds from the government budget are needed. The government commits to use the following self-financing tax-subsidy scheme:

(i) Both firms pollute	Emissions tax t^0
(ii) One firm pollutes	Subsidy to the non-polluting firm, financed by the taxation of the polluting firm (tax-subsidy-rule)
(iii) No firm pollutes	No taxes or subsidies

If both firms pollute, the regulator passes on the gains from taxation as a lump-sum transfer to the consumers. If only one firm pollutes, the tax-subsidy-rule is used and we have: The non-polluting firm is subsidized by s, which denotes the subsidy per unit of product sold, and the polluting firm is taxed by t, which denotes the emission tax per unit of product sold. The regulator has two choices. He can announce a subsidy rate denoted by s^{ann} or he can announce a tax rate denoted by t^{ann}; either rate is determined by the self-financing condition. To describe subsidization and taxation, suppose that (without loss of generality) firm 1 does not pollute and firm 2 does. Then, the regulation of the two possible scenarios looks as described in the following two subsections.

4.4 Announcement of the Subsidy Rate

The regulator announces the subsidy rate s^{ann}: The polluting firm 2 has to pay the tax rate

$$t = \begin{cases} \min\{s^{ann} q_1, \max\{\Pi_2^*, 0\}\}/q_2 & \text{if } q_2 > 0 \\ 0 & \text{else} \end{cases} \tag{6}$$

and the non-polluting firm 1 is subsidized by the rate

$$s = \begin{cases} \min\{s^{ann}, \max\{\Pi_2^*/q_1, 0\}\} & \text{if } q_1 > 0 \\ 0 & \text{else} \end{cases} , \tag{7}$$

whereby Π_2^* denotes the second firm's pretax net profit (the net profit without consideration of tax payment tq_2). By these rules the regulator always ensures that the self-financing condition (the gains from taxation equal the subsidy outlays) is fulfilled in any case, that is for any combination of q_1, q_2 and s^{ann}. Therefore there are no incentives for firm 2 to attempt to violate the self-financing condition. If the implementation of s^{ann} would violate the self-financing condition given the production quantities q_1 and q_2, rules (**??**) and (**??**) would lead to a downward adjustment of s and t until the self-financing condition is fulfilled.

The regulator maximizes social welfare by announcing the subsidy rate $s^{ann} = s^* = \frac{3\sqrt{5}-5}{10}$, which means that s^* is an element of the subgame perfect equilibrium of our five-stage game.[3] We define

Definition 3 *The use of the tax-subsidy scheme with the announcement of the subsidy rate s^* is denoted by **s-REG**.*

4.5 Announcement of the Tax Rate

The regulator announces the tax rate t^{ann}: Net profits Π_1 and Π_2 are realized. The regulator taxes the polluting firm 2 by the tax rate

$$t = \begin{cases} \min\{t^{ann}, \max\{\Pi_2^*/q_2, 0\}\} & \text{if } q_2 > 0 \\ 0 & \text{else} \end{cases} \tag{8}$$

and subsidizes the non-polluting firm 1 by the subsidy rate

$$s = \begin{cases} \min\{tq_2, \max\{\Pi_2^*, 0\}\}/q_1 & \text{if } q_1 > 0 \\ 0 & \text{else} \end{cases}, \tag{9}$$

whereby Π_2^* again denotes the second firm's pretax net profit. As before, rules (**??**) and (**??**) provide for the fulfillment of the self-financing condition.

[3] A proof is available upon request.

The regulator maximizes social welfare by announcing the tax rate $t^{ann} = t^* = \frac{1}{2}$ if the following condition holds:[4]

$$\min_{t\in[0,t^*]} \frac{\partial D(E)}{\partial E(t)} > \frac{1}{4x}, \tag{10}$$

whereby x denotes emissions per unit of polluting output, denoted by Q_E. As an example, consider section **??**, where a linear damage function $D(Q_E) = eQ_E$ is assumed. There, the condition (**??**) is fulfilled if $e > \frac{1}{4}$. To let our analysis not become to complex, we assume that the regulator can commit to implement the rate t^*. If (**??**) holds, this assumption does not influence the results. In other cases it would be possible, that the regulator could increase W by implementing another tax rate if just one firm uses the environmentally friendly technology. But in all cases the commitment to t^* yields the highest investment incentives, wherefore this regulation measure is interesting as a benchmark. We define:

Definition 4 *The use of the tax-subsidy scheme with the announcement of the tax rate t^* is denoted by **t-REG**.*

5 Tax-Subsidy Scheme versus Standard Emission Taxation

In this section we compare tax-REG, s-REG and t-REG. Do s-REG or t-REG in certain situations yield a higher social welfare W than the traditional emission taxation (tax-REG), and if yes, under which conditions?

It is desired from a social welfare point of view, that HUP^L and HUP^I become ceteris paribus mitigated. But solving one of the two hold-up problems does not automatically yield an increase in the expected social welfare, $Exp[W]$, since different regulatory measures typically affect several variables, namely the investment decision I, the licence decision and

[4] A proof is available upon request.

the production quantities q_i.[5] It could happen, for example, that one regulatory measure causes less emissions due to higher I, but stronger product market distortions than another measure.

5.1 Solving Hold-up Problems

We now turn our attention to both hold-up problems and analyze the investment as well as the licensing decisions. The firm's investment decision under a certain regulation (REG) is denoted with I^*_{REG}. In most cases, it is possible to rank I^*_{REG} under the different regulations if HUP^I exists. The results are summarized in the following proposition:[6]

Proposition 1 *If HUP^I exists, we have*

$$I^*_{tax-REG} < I^*_{s-REG} \quad \textit{if } t^K \leq \frac{2}{5} \tag{11}$$

and

$$I^*_{s-REG} \leq I^*_{t-REG}. \tag{12}$$

The existence of HUP^I means, that the firms invest less than the social welfare maximizing amount under tax-REG. From proposition **??** follows, that t-REG always solves HUP^I. s-REG solves HUP^I if $t^K \leq \frac{2}{5}$, which implies a relatively small marginal damage of emissions. Increasing I by using another regulation than tax-REG when HUP^I exists is denoted by "solving HUP^I". If $t^K \leq \frac{2}{5}$ holds, both s-REG and t-REG solve HUP^I. t-REG brings about a higher investment level I than s-REG.

Next, we consider the effects of the different regulations on the licensing decision. Assume temporarily, that only one firm has had success in developing the environmentally friendly

[5] The definition of solving HUP^L or HUP^I is given in the following subsection.

[6] A proof is available upon request.

technology. In the equilibrium, the other firm will become a licensee of the technology if the regulator uses s-REG. If the regulator uses t-REG in that situation, no licensing will take place. Under tax-REG, a licensing will take place if and only if $t^K > \frac{2}{5}$, which implies HUP^L. This brings us to our second proposition:[7]

Proposition 2 *s-REG solves HUP^L and t-REG does not.*

We denote the licensing due to the use of a regulatory measure in a situation where only one firm has had success in developing the non-polluting technology and where HUP^L exists by "solving HUP^L".

5.2 Welfare Comparison

In this subsection we analyze the implications of the different regulatory measures with respect to the expected social welfare $Exp[W]$, denoted by $Exp[W^{REG}]$. Comparing s-REG and tax-REG yields the following proposition:[8]

Proposition 3 *Given $t^K \leq \frac{2}{5}$ and $I^*_{s-REG} \leq I^{opt}_{tax-REG}$ holds. Then we have*

$$Exp[W^{s-REG}] > Exp[W^{tax-REG}]. \tag{13}$$

Here, $I^{opt}_{tax-REG}$ denotes the welfare optimal investment level under tax-REG. The conclusion of proposition **??** could be phrased as follows: Assume the current regulation is tax-REG, HUP^L does not exist, and I^*_{s-REG} is smaller than $I^{opt}_{tax-REG}$. Then the regulator can increase the expected social welfare $Exp[W]$ by using s-REG instead of tax-REG.

The comparison of t-REG and tax-REG results in the following proposition:[9]

[7] A proof is available upon request.
[8] A proof is available upon request.
[9] A proof is available upon request.

Proposition 4 *Given $t^K = \frac{1}{2}$ holds. Then we have*

$$Exp[W^{t-REG}] = Exp[W^{tax-REG}]. \tag{14}$$

From proposition **??** follows, that the expected social welfare $Exp[W]$ is the same under t-REG and tax-REG if the marginal emission damage is that high, that the regulator picks a tax rate t^K as high as possible, which means $t^K = \frac{1}{2}$. The intuition is as follows: The regulation of t-REG and tax-REG differ only if exactly one firm uses the non-polluting technology. The tax rate $t^K = \frac{1}{2}$ yields the same equilibrium under t-REG and tax-REG since the non-polluting firm becomes a monopolist in both cases. Because we seek the welfare best of the three regulatory measures, but can not entirely compare the measures in the current framework, we specify S and Θ in the following section to come to additional insights.

6 Analysis with Specification of S and θ

In this section we specify the damage function S and the function of the discovery probability Θ so as to compare tax-REG, s-REG, and t-REG on the basis of these parameters. We determine, which of the three regulatory mechanisms yields a higher expected social welfare $Exp[E]$ under which circumstances. In doing so, we discuss whether the result is dependent on the parameter that characterizes the damage function S.

6.1 Model

Since our analysis using the damage function D did not yield a complete ranking order of our three measures with respect to maximizing expected social welfare $Exp[W]$, we specify S to get information about the situation with HUP^{I}Additionally, we replace the condition for the existence HUP^I, namely $t^K > \frac{2}{5}$ with a condition dependent on D. We assume the following emission damage function D, which has a constant marginal damage of the emission generating production quantity Q_E:

$$D(Q_E) = eQ_E, \tag{15}$$

with $e > 0$.

Now, the inverse demand function $p = 1 - bQ$ and the damage function $D = eQ_E$ are parameterized and can be characterized by b and e, respectively. We can deduce the following corollary since $e > \frac{7}{30}$ holds if and only if $t^K > \frac{2}{5}$ holds:

Corollary 1 *We have*

$$HUP^L \Longleftrightarrow e > \frac{7}{30}. \tag{16}$$

For the sake of simplicity we assume the following function of the discovery probability:

A Firm i ($i = 1, 2$) develops the emission abatement technology with the probability

$$\Theta(I_i) = \begin{cases} \sqrt{I_i} & \text{if } I_i \leq (1-\varepsilon)^2 \\ 1-\varepsilon & \text{if } I_i > (1-\varepsilon)^2 \end{cases}, \tag{17}$$

if it invests I_i in R&D. ($0 < \varepsilon << 1$)

Assuming this functional form of Θ necessitates that no firm invests more than $(1-\varepsilon)^2$ in R&D. Since no profit maximizing firm will invest more than the monopoly profit in R&D, which is $\frac{1}{4b}$, the following assumption ensures investments smaller than $(1-\varepsilon)^2$ if ε is chosen sufficiently small:

$$b > \frac{1}{4}. \tag{18}$$

6.2 Analysis

In this subsection, we figure out, which of the three alternative mechanisms maximizes the expected social welfare $Exp[W]$. We start with the comparison of s-REG and t-REG.

6.2.1 Comparison of s-REG and t-REG

The comparison of $Exp[W^{s-REG}]$ and $Exp[W^{t-REG}]$ for different ranges of e yields the following result. We have

$$Exp[W^{s-REG}] > Exp[W^{t-REG}] \tag{19}$$

for all e (> 0) and all b $(\geq \frac{1}{4})$.[10] It turns out that s-REG is preferable compared to t-REG, since s-REG yields a higher $Exp[W]$ in the equilibrium. No we compare the preferable alternative, s-REG, with the standard emission taxation tax-REG, to investigate the best of the three considered alternatives. We do not have to consider t-REG any more, since it is dominated by s-REG.

6.2.2 Comparison of s-REG and tax-REG

Similar to the preceding subsection, we compare $Exp[W^{s-REG}]$ and $Exp[W^{tax-REG}]$ for different ranges of e and come to the following conclusion. We have

$$Exp[W^{s-REG}] > Exp[W^{tax-REG}] \tag{20}$$

if $e > \frac{3b}{36b-1}$.[11] This means that s-REG dominates both t-REG and tax-REG with respect to maximizing the expected social welfare $Exp[W]$, if $e > \frac{3b}{36b-1}$ holds. The regulator should use s-REG if the emission damage D has a relatively strong influence on the social welfare W $(e > \frac{3b}{36b-1})$. s-REG leads to a lower $Exp[W]$ if e is smaller than $\frac{3b}{36b-1}$, which is intuitive. If the marginal damage from emissions is relatively small $(e < \frac{3b}{36b-1})$, then the damage of emissions D becomes rather meaningless and it is not worth to invest in R&D. In such a situation, tax-REG is preferable over s-REG, since firms invest less under tax-REG.

We consider two examples with a non-linear marginal damage of emissions. In both examples, s-REG yields the highest expected social welfare.

[10] A proof is available upon request.

[11] A proof is available upon request.

Example 1 $b = 1$, $D = (Q_E)^2$. *We have*

$$Exp[W^{s-REG}] \approx 0,198677 > Exp[W^{tax-REG}] \approx 0,197824 > Exp[W^{t-REG}] \approx 0,186827. \tag{21}$$

Example 2 $b = 1$, $D = 3(Q_E)^2$. *We have*

$$Exp[W^{s-REG}] \approx 0,123119 > Exp[W^{tax-REG}] \approx 0,111699 > Exp[W^{t-REG}] \approx 0,111682. \tag{22}$$

6.3 Results

In this section we have assumed a constant marginal damage of emissions and have in particular assumed a damage function of the form $D = eQ_E$. Furthermore, we have assumed that a firm develops the environmentally friendly technology with the probability $\Theta = \sqrt{I_i}$ $(i = 1, 2)$. In this situation, $Exp[W^{s-REG}] > Exp[W^{t-REG}]$ holds for the whole range of the damage parameter e. Additionally, $Exp[W^{s-REG}] > Exp[W^{tax-REG}]$ holds if $e > \frac{3b}{36b-1}$. Therefore s-REG dominates the other two regulatory measures, if the marginal damage of emissions exceeds a certain level, which is the more interesting case.

7 Conclusions

In the present paper we considered hold-up problems in the context of environmental R&D investments and licensing of environmentally friendly technologies. We analyzed whether hold-up problems in a Cournot-duopoly can be solved by using self-financing tax-subsidy schemes and whether one can increase social welfare by using these schemes instead of a standard emission taxation. The hold-up problems were defined under an emission taxation regime.

Two different types of hold-up-problems can occur. The first hold-up problem is the problem with respect to the investment decision and the second problem is the one with respect to the licence decision. In our analysis, we have compared the standard emission taxation and two different tax-subsidy schemes, namely one with the announcement of the subsidy rate and one with the announcement of the tax rate. If exactly one firm has developed an environmentally friendly technology, then the tax-subsidy scheme with the announcement of the tax rate does not yield the licensing of the technology, whereas the tax-subsidy scheme with the announcement of the subsidy rate always yields the licensing. That is why only the announcement of the subsidy rate solves the hold-up problem with respect to licensing. But the tax-subsidy scheme with the announcement of the tax rate yields the highest investment expenditures in R&D of environmentally friendly technologies, wherefore the announcement of the tax rate is best in solving hold-up problems with respect to the investment decision.

In a specified model with a constant marginal damage of emissions, we have compared the expected social welfare under the three regulatory measures. It turns out that the tax-subsidy scheme with the announcement of the subsidy rate dominates both, the tax-subsidy scheme with the announcement or the tax rate and the standard emission taxation, if the marginal damage of emissions exceeds a certain level. Two examples with a non-linear marginal damage of emissions yielded the same result.

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