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ARILD HEIMVIK

REFUNDED EMISSION PAYMENTS SCHEME – A COST-EFFICIENT *AND* POLITICALLY ACCEPTABLE INSTRUMENT FOR REDUCTION OF NO_x-EMISSIONS?

Department of Economics
UNIVERSITY OF BERGEN

Refunded emission payments scheme – a cost-efficient *and* politically acceptable instrument for reduction of NO_x-emissions?[1]

Arild Heimvik[2]

Abstract

The paper studies the effectiveness of a refunded emission payments (REP) scheme in achieving a specific target path of NO_x-emission reductions. A REP scheme levies a charge on emissions and refunds the collected funds back to the emitting firms. REP schemes have been highlighted as a remedy to some concerns about standard emission taxes. The purpose of a REP scheme, however, is to achieve effective emission reductions. We examine two REP designs in this paper and analyze their incentives for emission mitigation at the firm level, with heterogenous firms. In the first design, refunds are given to firms based on their emission cuts. The second design gives refunds based on output shares of the emitting firms. Results show that while both designs can achieve the specific target path, only refunding based on emission-reductions is cost-efficient. The two designs target different objectives and hence, provide different mitigation incentives, and result in different distributional outcomes. On the other hand, neither design raises governmental revenue, nor do they strictly adhere to the polluter-pays-principle. However, a REP scheme has qualities that should make it appealing to regulators, especially if an effective emission tax is unfeasible.

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[2] Department of Economics, University of Bergen, e-mail: arild.heimvik@uib.no

1. Introduction

Refunded emission payments (REP) scheme is a policy instrument that has garnered attention to overcome some problematic issues associated with the standard Pigouvian tax. With a REP scheme, a charge is put on emission and the collected revenue is recycled back to the emitting firms. It could increase public support for emission regulations through refunding (Aidt, 2010; Fredriksson & Sterner, 2005; Kallbekken, Kroll, & Cherry, 2011) and make it possible to introduce efficient emission charges (Johnson, 2007; Sterner & Isaksson, 2006). It could also address concerns about competitiveness[3] (Sterner & Isaksson, 2006) and emission leakage (Bernard, Fischer, & Fox, 2007; Fischer & Fox, 2012; Fischer, Greaker, & Rosendahl, 2017).

The main objective of a REP scheme, however, is to achieve effective emission mitigation. Hence, this paper analyzes two different designs of a REP scheme in order to assess whether a REP scheme can be used as a cost-efficient instrument for mitigation of nitrogen oxide (NO_x) - emissions over time. The main focus in the literature has been on output-based refunding (Fischer, 2011; Gersbach & Requate, 2004; Sterner & Isaksson, 2006). We analyze a scheme where refunds are based on emissions cuts and compare it with an output-based scheme due to its prominence in the literature. By assumption, there is a binding path of emission reductions set by the regulator that firms must adhere to and the optimal emission tax is not an available instrument for the regulator, due to lack of political acceptance. We examine the incentives for compliance on the firm level under the two different versions of a REP scheme. Firms emit through their production and emissions can be mitigated either with production adjustments or use of abatement technology. An optimal instrument incentives firms to choose the cost-minimizing combination of these two measures. Previous contributions to the literature have used static models, this paper expands the literature by using a dynamic model. Comparative statics and an illustrative simulation model are used to gain more insight from the theoretical results.

Gersbach and Requate (2004), argue that a refunding scheme based on the market shares of firms could be harmful under perfect competition, but could improve welfare under imperfect competition. Fischer (2011) acknowledges that a production subsidy can remedy the problem of insufficient provision of output. However, an endogenous refund in an asymmetric Cournot duopoly result in too high levels of output and emissions, compared to a fixed rebate for the

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[3] A caveat however is that a refund system could lead to excessive entry into the market. To avoid this, Cato (2010) argues that a tax-refund system should be coupled with an entry-license tax.

same emission intensity. Hagem et.al. (2012) and Hagem et.al. (2015) use a static model to compare two REP schemes where refunds are given in proportion to output and as a share of expenditures for abatement equipment. They find that both schemes result in cost-inefficient abatement reduction, compared to a Pigouvian tax. Bontems (2019) also examines a three-part instrument, where a emission charge is combined with both output- and expenditure-based refunding. He shows that such an instrument can help to remedy the drawbacks from REP schemes where refunds are given for either output or subsidies for abatement equipment. Others have argued that output-based refunding has a considerable positive impact for adoption of abatement technologies (Bonilla, Coria, Mohlin, & Sterner, 2015; Sterner & Turnheim, 2009). Coria and Mohlin (2017), however, show that although a REP scheme can expedite diffusion of abatement technologies, it is not unambiguous whether a REP scheme provides better incentives than a standard emission tax for technological upgrades over time.

Since 1992, Sweden has used a scheme that refunds in proportion to output (Sterner & Isaksson, 2006). In France, firms can apply for the collected funds as subsides for abatement measures (Millock & Nauges, 2006; Millock, Nauges, & Sterner, 2004). Since 2008, Norway has used a REP scheme, dubbed the NO_x -fund. This is a voluntary scheme where the participating firms are exempt from a NO_x -tax levied by the government. The firms pay an emission charge up front into the fund that is refunded in accordance with verified emission reductions (Hagem, Holtsmark, & Sterner, 2014). Although REP schemes are less widespread than emission taxes and emission permit markets, there has been some interest surrounding the scheme. In Norway, there have been discussions concerning the use of a REP scheme to reduce CO_2-emissions from the transport sector (Pinchasik & Hovi, 2017). Since REP schemes are more recent additions as environmental policy instruments, they are interesting to study to evaluate their potential.

The rest of the paper is organized as follows: In section 2, the theoretical model and its assumptions are introduced. Section 3 begins by introducing a scenario with the socially optimal solutions. Next, the two versions of the REP scheme are presented. Results from the model are discussed in section 4, and comparative statics and an illustrative numerical model are applied. The paper is summarized and concluding remarks are delivered in section 5.

2. The model

The model focuses on energy producing firms that emit NO_x as part of their production process through combustion of oil, gas and biofuel. NO_x are waste gases with detrimental effects on health and the ecosystem that lead to eutrophication, acid rain and increased concentrations of ground-level ozone (Hagem et al., 2015). For simplicity, we shall assume a proportional relationship between energy production and emission of NO_x. The regulator announces a target path of NO_x-emission cuts to be achieved for the regulated firms. There are two ways for the firms to reduce their emissions. They can either reduce production or invest in more abatement technology. In this paper, there is one type of abatement technology[4] that is relevant[5].

The firms in the model are heterogenous. Hence, we examine how different types of firms adapt under the two policy instruments. In order to do this, we change one characteristic, while keeping all else constant. The regulated sectors consist of many firms, so by assumption, they do not have market power. There are N profit-maximizing firms, where an arbitrarily chosen firm among these is analyzed. The target path of emission reductions spans over several periods. This is in accordance with the way such targets are set in practice. Both Norway and Sweden have committed themselves to reduction of NO_x-emissions over a given period of time, in accordance with the Gothenburg Protocol (Hagem et al., 2015).

The model is dynamic and uses optimal control theory to highlight the accumulation of abatement technology required to meet the specific target path. The stock of technology represents the state variable and investments in new technology represents the control variable. Depreciation of existing stock of technology captures maintenance costs for installed capacity.

The model uses the following symbols and functional expressions

- m_{it}: Level of NOx at date t for firm i
- $\widehat{\mathrm{m}}_{i}$: Unregulated level of NOx for firm i
- $\mathrm{m}_{\mathrm{it}}^{*}$: Target level of NOx at date t for firm i
- q_{it}: Production at date t for firm i
- K_{it}: Capacity of abatement technology at date t for firm i
- τ_{t}: Optimal emission fee at date t

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[4] The technology can be thought of as end-of-pipe technology. This is an add-on measure used to comply with environmental regulations, that reduces harmful substances arising as by-products from production. Examples are scrubbers and catalytic converters (Frondel, Horbach, & Rennings, 2007). Bonilla et al. (2015) also argue that the use of a REP scheme has a positive effect on the adoption of end-of-pipe post combustion technologies.

[5] This is the same assumption made in (Hagem et al., 2015).

- ρ_t: REP charge in the emissions reductions REP scheme at date t
- φ_t: Support rate in the emissions reductions REP scheme at date t
- β: Share of refund in the emissions reductions REP scheme, with $\beta \in (0,1)$
- $\beta\varphi_t$: Refund in the emissions reductions REP scheme
- μ_t: REP charge in the output REP scheme at date t
- σ_t: Support rate in the output REP scheme at date t
- θ_i: Marginal effect of production on emissions for firm i, with $0 < \theta < 1$
- α_i: Marginal effect of abatement technology on emissions for firm i, with $0 < \alpha < 1$
- r: Market discount rate
- δ: Depreciation rate of abatement technology capacity
- T: Termination date of problem considered

- $\pi_i(q_{it})$: Profit for firm i at date t, with $\frac{\partial \pi_i(q_{it})}{\partial q_{it}} < 0$,
- $m_{it}(q_{it}, K_{it})$: Emissions function for firm i at date t , with $\frac{\partial\, m_{it}}{\partial\, q_{it}} > 0, \frac{\partial^2\, m_{it}}{\partial\, {q_{it}}^2} \geq 0, \frac{\partial\, m_{it}}{\partial\, K_{it}} < 0, \frac{\partial^2\, m_{it}}{\partial\, {K_{it}}^2} \geq 0$ and $\frac{\partial^2\, m_{it}}{\partial\, q_{it}\, \partial\, K_{it}} = 0$
- $h_i(K_{it})k_{it}$: Cost function for capacity of abatement technology for firm i at date t, with $\frac{\partial h_i}{\partial K_{it}} > 0, \frac{\partial^2 h_i}{\partial {K_{it}}^2} > 0$
- $\dot{K}_{it}$: Development of stock of abatement technology for firm i at date t, with $\dot{K}_{it} = k_{it} - \delta K_{it}$
- k_{it}: Investment in new capacity of abatement technology for firm i at date t, with. $k_{it} \geq 0$

3. Analysis

3.1.Emission constrained social optimum

The regulation in this section results in a cost-efficient combination of production adjustments and investment in abatement technology. The solutions obtained in this section will be referred to as solutions of the social optimum, or socially optimal solutions. The optimization problem reads:

$$\max \int_0^T \sum_{i=1}^{n} [\pi_i(q_{it}) - h_i(K_{it})k_{it}]e^{-rt} + \eta_t \sum_{i=1}^{n} (m_{it}^* - m_{it})$$

subject to:

$$\dot{\mathrm{K}}_{\mathrm{it}} = \mathrm{k}_{\mathrm{it}} - \delta \mathrm{K}_{\mathrm{it}}$$

Denoting the co-state variable λ_{it}, the corresponding present-value Hamiltonian reads:

$$\mathrm{H}_{\mathrm{t}} = \sum_{i=1}^{n} [\pi_i(\mathrm{q}_{\mathrm{it}}) - \mathrm{h}_i(\mathrm{K}_{\mathrm{it}})\mathrm{k}_{\mathrm{it}}]\mathrm{e}^{-\mathrm{rt}} + \sum_{i=1}^{n} \lambda_{\mathrm{it}}(\mathrm{k}_{\mathrm{it}} - \delta\mathrm{K}_{\mathrm{it}}) + \eta_{\mathrm{t}} \sum_{i=1}^{n} (\mathrm{m}_{\mathrm{it}}^{*} - \mathrm{m}_{\mathrm{it}})$$

The first-order conditions are:

1) $\frac{\partial \mathrm{H}_{\mathrm{t}}}{\partial \mathrm{q}_{\mathrm{it}}} = [\pi'_i(\mathrm{q}_{\mathrm{it}})]\mathrm{e}^{-\mathrm{rt}} - \eta_{\mathrm{t}}\mathrm{m}_{\mathrm{iq}} = 0$
2) $\frac{\partial \mathrm{H}_{\mathrm{t}}}{\partial \mathrm{k}_{\mathrm{it}}} = -\mathrm{h}_i(\mathrm{K}_{\mathrm{it}})\mathrm{e}^{-\mathrm{rt}} + \lambda_{\mathrm{it}} = 0$
3) $\frac{\partial \mathrm{H}_{\mathrm{t}}}{\partial \mathrm{K}_{\mathrm{it}}} = -\mathrm{h}'_i(\mathrm{K}_{\mathrm{it}})\mathrm{k}_{\mathrm{it}}\mathrm{e}^{-\mathrm{rt}} - \delta\lambda_{\mathrm{it}} - \eta_{\mathrm{t}}\mathrm{m}_{\mathrm{iK}} = -\dot{\lambda}_{\mathrm{it}}$
4) $\lambda_{\mathrm{iT}} \geq 0$
5) $\mathrm{H}_{\mathrm{T}} = \sum_{i=1}^{n}[\pi_i(\mathrm{q}_{\mathrm{iT}}) - \mathrm{h}_i(\mathrm{K}_{\mathrm{iT}})\mathrm{k}_{\mathrm{iT}}]\mathrm{e}^{-\mathrm{rT}} + \sum_{l=1}^{n} \lambda_{\mathrm{iT}}(\mathrm{k}_{\mathrm{iT}} - \delta\mathrm{K}_{\mathrm{iT}}) + \eta_{\mathrm{T}} \sum_{i=1}^{n}(\mathrm{m}_{\mathrm{iT}}^{*} - \mathrm{m}_{\mathrm{iT}})$

Using 2) and 3) to solve for the shadow constraint of the emission reductions (η_{t}) ,results in:

6) $\eta_{\mathrm{t}} = -\frac{(\mathrm{r}+\delta)\mathrm{h}_i(\mathrm{K}_{\mathrm{it}}) + \mathrm{h}'_i(\mathrm{K}_{\mathrm{it}})\delta\mathrm{K}_{\mathrm{it}}}{\mathrm{m}_{\mathrm{iK}}}\mathrm{e}^{-\mathrm{rt}}$

Inserting 6) into 1), we obtain the optimality conditions:

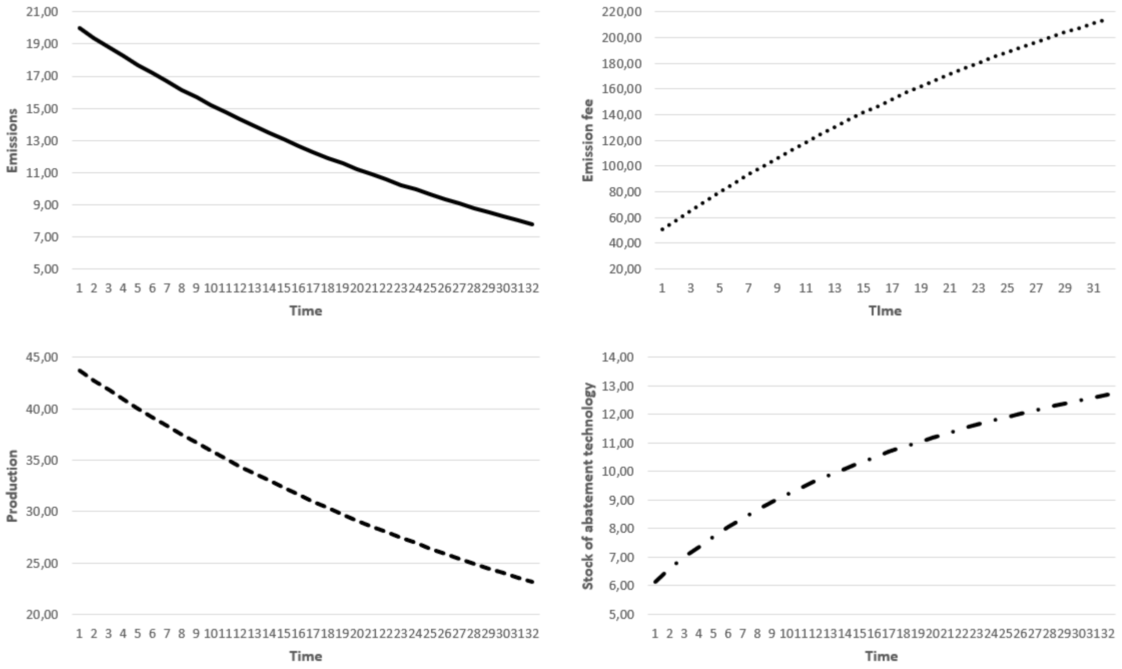
7) $\frac{\pi'_i(\mathrm{q}_{\mathrm{it}})}{\mathrm{m}_{\mathrm{iq}}} = -\frac{(\mathrm{r}+\delta)\mathrm{h}_i(\mathrm{K}_{\mathrm{it}}) + \mathrm{h}'_i(\mathrm{K}_{\mathrm{it}})\delta\mathrm{K}_{\mathrm{it}}}{\mathrm{m}_{\mathrm{iK}}} = \eta_{\mathrm{t}}\mathrm{e}^{\mathrm{rt}}$

The optimality conditions in 7), show that the marginal costs of reducing emissions, divided by the marginal effect of emission reductions, must be equal for both mitigation measures. In turn, these must be equal to the shadow cost of achieving the target path of emission reductions. Since the firms in the model are heterogenous, there are different ways they can meet the target path. The shadow cost of the emission cuts, however, is equal for all firms. If emissions are reduced through production reductions, the marginal cost of emission reductions is the foregone marginal profit. This cost is divided by the effect of one less unit produced on emission reductions. If a firm cuts emission through investment in abatement technology, the marginal cost is the extra abatement costs. Technology is a durable good in this model, one extra unit of technology therefore increases both the capacity cost of the current stock as well as the added capacity cost. This is divided by the marginal effect of technology on emission reductions.

If the regulator introduces an optimal emission tax τ_t, equal to the shadow cost of emission reductions (from 7)), the socially optimal solutions can be achieved. The optimal emission tax increases in both measures of emission mitigation. A key assumption in this paper, however, is that the optimal emission tax is politically unfeasible. Hence, in the following, it is assumed that the regulator will use a REP scheme to achieve the specific target path.

The socially optimal solutions can be illustrated, with a numerical model[6]. For simplicity, there are N identical firms. Hence, all firms make the same decision under regulation. The purpose is to show the adjustments made to achieve the target path of emission reductions, as well as the path of the emission tax required to meet this path.

Figure 1: Illustration of socially optimal solutions



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[6] The functional forms used are listed in Appendix A.

The graph in the top left corner of Figure 1 is the target path of NO_x-emission reductions. The graph on the top right corner shows the path of the emission tax. In order to reduce emissions in accordance with the target path, the tax increases over time. The two graphs at the bottom show the production path (left) and the stock of abatement technology (right).

In the next sections the designs of the REP schemes and examined on how they perform compared to the solutions of the social optimum. First, we analyze a version where firms receive a refund in proportion to their verified emission cuts. Then, we examine a version where refunds are given in proportion to the firms' output. With the use of comparative statics, the two instruments are compared to see how changes in parameters impact the adaptations made by the firms. The results are also highlighted using an illustrative numerical model.

3.2.Refunds based on emission reductions

The REP scheme in this section is based on the scheme currently used in Norway. In 2007, Norway introduced a tax on NO_x-emissions for specified sources[7]. As a response to the tax, different business organizations came together and proposed a solution, called the NO_x-fund which came into effect in 2008. The purpose of the fund was to reduce NO_x-emissions and contribute to meeting Norway's obligation under the Gothenburg Protocol (NOx-avtalen 2018-2025, 2017). The fund is a voluntary arrangement where the participating business organizations pay a charge to the fund per kilogram of NO_x emitted. These revenues are then recycled back to the same firms based on verified emission cuts (NOx-fondet, 2019). If the firms meet their obligations through the NO_x-fund, they are exempted from the NO_x-tax introduced by the government. If the firms are non-compliant however, they must pay the tax in proportion to their emissions and receive no refund (NOx-avtalen 2018-2025, 2017).

The Norwegian REP scheme has been examined previously in Hagem et.al. (2015), where the scheme is modeled differently from this paper. There, the refund is defined as a share of a firm's abatement costs and is not tied directly to the its emissions cuts.

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[7] The fee was levied on NO_x-emissions in energy production from: **1)** propulsion machinery with total installed effect on more than 750 kW **2)** engines, boilers and turbines with a total effect of more than 10 MW and **3)** flares on offshore installations and onshore facilities. These sources comprise about 55 per cent of the total NOx-emissions in Norway (Hagem et al., 2014).

In this paper, we analyze whether a REP scheme can be an efficient instrument for reducing NO_x-emissions. The design examined in this section, links the refund directly to firms' emission cuts. There are basically two ways of reducing emissions, either through reduced production or increased abatement. An efficient instrument should allow for flexibility to use both measures. In published guides to the NO_x-fund, it is specified that the refund rate is given in proportion to annual NOx-reductions, which coincides with the setup used in this paper. In addition, the refund cannot exceed 70 per cent of the cost of the NOx-reducing measure (NOx-fondet, 2019, p. 6). This feature is also included in the derivation of the optimal refund for in this section.

In the rules for the NO_x-fund, refunds to firms are restricted to include abatement measures in the form of technical installations on both existing and new sources of emissions (NOx-fondet, 2019, p.6). This is similar to the way the refund is modeled in Hagem et.al. (2015). In this paper, refunds are linked directly to firms' emission cuts for two reasons. First, the NO_x-fund incentivizes emission cuts and refunds are given in proportion to verified NO_x-emission cuts. Second, we show that it will be optimal to refund based on emission cuts and added restrictions will hamper the efficiency of the instrument.

The optimization problem for the firms read:

$$\max \int_{0}^{\mathrm{T}} \sum_{i=1}^{n} [\pi_i(\mathrm{q_{it}}) - \mathrm{h}_i(\mathrm{K_{it}})\mathrm{k_{it}} - \rho_\mathrm{t}\mathrm{m_{it}} + \beta\varphi_\mathrm{t}(\widehat{\mathrm{m}}_\mathrm{i} - \mathrm{m_{it}})]\mathrm{e}^{-\mathrm{rt}}$$

subject to:

$$\dot{\mathrm{K}}_{\mathrm{it}} = \mathrm{k_{it}} - \delta \mathrm{K_{it}}$$

Refunds are given in accordance with verified emissions cuts, where $\widehat{\mathrm{m}}_\mathrm{i}$ expresses the emission by the individual firm with no mitigation measures. If there are no emission regulations, then from 1), the firm upholds production until marginal profit is zero. There is no incentive to invest in abatement technology, hence, the unregulated emission level is constant over time[8].

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[8] This result is conditional upon an emission function without drift over time. If drift is included, unregulated emission for the firm would be time-variant. This is however not pursued further in this paper.

Denoting the co-state variable ξ_{it}, the corresponding present-value Hamiltonian reads:

$$\mathrm{H_t} = \sum_{i=1}^{n} [\pi_i(\mathrm{q_{it}}) - \mathrm{h}_i(\mathrm{K_{it}})\mathrm{k_{it}} - \rho_\mathrm{t}\mathrm{m_{it}} + \beta\varphi_\mathrm{t}(\widehat{\mathrm{m}}_\mathrm{i} - \mathrm{m_{it}})]\mathrm{e}^{-\mathrm{rt}} + \sum_{i=1}^{n} \xi_{\mathrm{it}}(\mathrm{k_{it}} - \delta\mathrm{K_{it}})$$

The first-order conditions are:

8) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{q_{it}}} = \left[\pi'_i(\mathrm{q_{it}}) - \rho_\mathrm{t}\mathrm{m_{iq}} - \beta\varphi_\mathrm{t}\mathrm{m_{iq}}\right]\mathrm{e}^{-\mathrm{rt}} = 0$

9) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{k_{it}}} = -\mathrm{h}_i(\mathrm{K_{it}})\mathrm{e}^{-\mathrm{rt}} + \xi_{\mathrm{it}} = 0$

10) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{K_{it}}} = -[\mathrm{h}'_i(\mathrm{K_{it}})\mathrm{k_{it}} + \rho_\mathrm{t}\mathrm{m_{iK}} - \beta\varphi_\mathrm{t}\mathrm{m_{iK}}]\mathrm{e}^{-\mathrm{rt}} - \delta\xi_{\mathrm{it}} = -\dot{\xi}_{\mathrm{it}}$

11) $\xi_{\mathrm{iT}} \geq 0$

12) $\mathrm{H_T} = \sum_{i=1}^{n}[\pi_i(\mathrm{q_{iT}}) - \mathrm{h}_i(\mathrm{K_{it}})\mathrm{k_{it}} - \rho_\mathrm{T}\mathrm{m_{iT}} + \beta\varphi_\mathrm{T}(\widehat{\mathrm{m}}_\mathrm{i} - \mathrm{m_{iT}})]\mathrm{e}^{-\mathrm{rT}} + \sum_{i=1}^{n} \xi_{\mathrm{iT}}(\mathrm{k_{iT}} - \delta\mathrm{K_{iT}})$

Using 9) and 10), we obtain:

$$\rho_\mathrm{t} + \beta\varphi_\mathrm{t} = -\frac{(\mathrm{r}+\delta)\mathrm{h}_i(\mathrm{K_{it}}) + \mathrm{h}'_i(\mathrm{K_{it}})\delta\mathrm{K_{it}}}{\mathrm{m_{iK}}}\mathrm{e}^{-\mathrm{rt}}$$

Inserting this into 8), we obtain the following optimality conditions:

13) $\frac{\pi'_i(\mathrm{q_{it}})}{\mathrm{m_{iq}}} = -\frac{(\mathrm{r}+\delta)\mathrm{h}_i(\mathrm{K_{it}}) + \mathrm{h}'_i(\mathrm{K_{it}})\delta\mathrm{K_{it}}}{\mathrm{m_{iK}}} = \rho_\mathrm{t} + \beta\varphi_\mathrm{t}$

The optimality conditions in 13) equal those of the social optimum in 7). A proper combination of the emission charge and the refund can achieve the socially optimal solutions. This combination is such that $\rho_\mathrm{t} + \beta\varphi_\mathrm{t} = \tau_\mathrm{t}$.

A key element with a REP scheme is revenue neutrality. Revenues are refunded back to the firms. The budget constraint is binding for the sum of all firms and can be expressed as:

14) $\rho_\mathrm{t}\sum_{i=1}^{n}\mathrm{m}^*_{\mathrm{it}} = \beta\varphi_\mathrm{t}\sum_{i=1}^{n}(\widehat{\mathrm{m}}_\mathrm{i} - \mathrm{m}^*{}_{\mathrm{it}})$.

With 13) and 14), we obtain an expression for the REP charge:

$$15)\ \rho_{\mathrm{t}} = \tau_{\mathrm{t}}\left(1 - \frac{\sum_{i=1}^{n} \mathrm{m}_{\mathrm{it}}^{*}}{\sum_{i=1}^{n} \widehat{\mathrm{m}}_{\mathrm{i}}}\right)$$

The REP charge is a share of the optimal emission tax, determined by the stringency of the emission regulations. The socially optimal solutions can then be achieved with a REP scheme where the charge is at a lower level than the optimal tax τ_{t}. Although they model the REP scheme based on the Norwegian NO_x-fund differently, Hagem et.al. (2015) also find that for a given target of emission cuts, the REP charge will be less than the standard emission tax. In the NO_x-fund, the charge is also at a lower level than the NO_x-tax set by the government. The reason is to create an incentive for firms to participate in the NO_x-fund, in addition to the refund firms receive f (NOx-fondet, 2018). The emission tax introduced by the government was set in accordance with a 2002 estimate of the marginal costs of NO_x-emission reductions and the initial level was 15 NOK per kilogram NO_x (St.prp. nr. 1 (2006-2007), 2006)[9]. Even though the REP charge was not set using the expression in 15), it was still determined as a share of the NO_x-tax set by the government, assuring that it did not exceed this level.

Taking the time derivative of 15) results in the time path for the charge:

$$16)\ \dot{\rho}_{\mathrm{t}} = \dot{\tau}_{\mathrm{t}}\left(1 - \frac{\sum_{i=1}^{n} \mathrm{m}_{\mathrm{it}}^{*}}{\sum_{i=1}^{n} \widehat{\mathrm{m}}_{\mathrm{it}}}\right) - \tau_{\mathrm{t}}\frac{\sum_{i=1}^{n} \dot{\mathrm{m}}_{\mathrm{t}}^{*}}{\sum_{i=1}^{n} \widehat{\mathrm{m}}_{\mathrm{i}}}$$

Since the target level of emissions decrease over time and the optimal tax increases to achieve this, the REP charge will also increase to ensure that the target path is met.

The refund can be expressed as:

$$17)\ \beta\varphi_{\mathrm{t}} = \tau_{\mathrm{t}}\frac{\sum_{i=1}^{n} \mathrm{m}_{\mathrm{it}}^{*}}{\sum_{i=1}^{n} \widehat{\mathrm{m}}_{\mathrm{i}}}$$

The refund increases with the optimal emission tax and decreases with more stringent emission cuts. The parameter β is an expression of the refund constraint in the NO_x-fund, where the refund cannot exceed 70 per cent of the cost of the NO_x-reducing measure. If the share β

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[9] More recent estimates however show that the costs are likely to be considerable higher, up to 50-60 NOK per kilogram NO_x (St.prp. nr. 1 (2006-2007), 2006)

increases, the support rate φ_t must increase to ensure that 17) holds, since the refund is determined by the optimal emission tax and the target of NOx-emission reductions.

The time path is obtained by taking the derivative of 17) with respect to time:

$$18)\ \beta\dot{\varphi}_t = \frac{\dot{\tau}_t \sum_{i=1}^{n} m_{it}^{*} + \tau_t \sum_{i=1}^{n} \dot{m}_t^{*}}{\sum_{i=1}^{n} \widehat{m}_i}$$

If $\dot{\tau}_t \sum_{i=1}^{n} m_{it}^{*} > (<) \tau_t \sum_{i=1}^{n} \dot{m}_t^{*}$, then the refund increases (decreases) over time.

3.3.Refunds based on output

This REP scheme is based on the Swedish version that came into effect in 1992. When Sweden settled on using a price mechanism for reducing NO_x-emissions, it was decided that a high price would be necessary to achieve substantial abatement measures. With the introduction of a REP scheme, it was possible to impose a high charge, since the net effect would be mitigated by the refund mechanism (Sterner & Isaksson, 2006). In the scheme, a charge is levied per kilogram of NO_x emitted and the collected funds are recycled back to the same firms in proportion to their output of useful energy[10] (Sterner & Isaksson, 2006). The refund given in proportion to output also made it possible to achieve both cuts in NO_x-emissions without having to reduce the activity level substantially in the regulated sectors[11].

Refund mechanisms based on output have by far received the most attention in the literature. It is therefore valuable to include such a scheme in the analysis. The model for the REP scheme in this section is based on the previous contributions in the literature (Gersbach & Requate, 2004; Sterner & Isaksson, 2006). Both apply the same static theoretical model to analyze a REP scheme where firms pay a charge per unit of emissions and receive a refund proportional to their output, In the following, the same assumptions as Sterner & Isaksson (2006) are applied, where the regulated firms act competetively and take market prices of

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[10] "Useful energy" is generally accepted as a benchmark for measuring output for industries as varied as those regulated under the Swedish REP scheme, since the primary goal of the scheme is to affect the combustion technologies. Useful energy for power plants and district heating plants equals the energy sold. For other industries, useful energy is comprised of hot water, steam or electricity produced in the boiler, used in heating or factory buildings or the production process (Sterner & Isaksson, 2006).

[11] Sweden introduced a REP scheme for NOx-emissions from stationary combustion engines, gas turbines and industrial boilers with a useful energy production of at least 50 GWh per year. The threshold was lowered to 25 GWh in 1997. The charge was initially set at 40 SEK and in 2008 it was increased to 50 SEK (Bonilla et al., 2015).

output and the actions of the other firms as given. Also, emission and outptut can be aggregated to suitable totals. There are N profit-maximizing firms, where the model focus on an arbitrarily chosen firm among these.

The optimization problem reads:

$$\max \int_{0}^{\mathrm{T}} \sum_{i=1}^{n} \left[\pi_i(\mathrm{q_{it}}) - \mathrm{h}_i(\mathrm{K_{it}})\mathrm{k_{it}} - \mu_\mathrm{t}\mathrm{m_{it}} + \sigma_\mathrm{t}\mathrm{q_{it}} \frac{\sum_{i=1}^{n} \mathrm{m_{it}}}{\sum_{i=1}^{n} q_{it}} \right] \mathrm{e}^{-\mathrm{rt}}$$

subject to:

$$\dot{\mathrm{K}}_\mathrm{it} = \mathrm{k_{it}} - \delta\mathrm{K_{it}}$$

In addition, the following also applies:

$$\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{m_{it}} = \mathrm{M_t}, \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{q_{it}} = \mathrm{Q_t} \text{ and } \mathrm{s_{it}} = \frac{\mathrm{q_{it}}}{\mathrm{Q_t}}$$

Denoting the co-state variable $\varepsilon_{\mathrm{it}}$, the corresponding present-value Hamiltonian reads:

$$\mathrm{H_t} = \sum_{i=1}^{n} \left[\pi_i(\mathrm{q_{it}}) - \mathrm{h}_i(\mathrm{K_{it}})\mathrm{k_{it}} - \mu_\mathrm{t}\mathrm{m_{it}} + \sigma_\mathrm{t}\mathrm{q_{it}} \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}} m_{it}}{\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{q_{it}}} \right] \mathrm{e}^{-\mathrm{rt}} + \sum_{i=1}^{n} \varepsilon_\mathrm{it}(\mathrm{k_{it}} - \delta\mathrm{K_{it}})$$

This results in the following first-order conditions:

19) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{q_{it}}} = \left[\pi'_\mathrm{i}(\mathrm{q_{it}}) - \mu_\mathrm{t}\mathrm{m_{iq}} + \sigma_\mathrm{t}\left(\frac{\mathrm{M_t}}{\mathrm{Q_t}} + \mathrm{s_{it}}\left(\mathrm{m_{iq}} - \frac{\mathrm{M_t}}{\mathrm{Q_t}} \right) \right) \right] \mathrm{e}^{-\mathrm{rt}} = 0$

20) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{k_{it}}} = -\mathrm{h}_i(\mathrm{K_{it}})\mathrm{e}^{-\mathrm{rt}} + \varepsilon_\mathrm{it} = 0$

21) $\frac{\partial \mathrm{H_t}}{\partial \mathrm{K_{it}}} = [-\mathrm{h}'_i(\mathrm{K_{it}})\mathrm{k_{it}} - \mu_\mathrm{t}\mathrm{m_{iK}} + \sigma_\mathrm{t}\mathrm{s_{it}}\mathrm{m_{iK}}]\mathrm{e}^{-\mathrm{rt}} - \delta\varepsilon_\mathrm{it} = -\dot{\varepsilon}_\mathrm{it}$

22) $\varepsilon_\mathrm{iT} \geq 0$

23) $\mathrm{H_T} = \sum_{i=1}^{n} \left[\pi_i(\mathrm{q_{iT}}) - \mathrm{h}_i(\mathrm{K_{iT}})\mathrm{k_{iT}} - \mu_\mathrm{t}\mathrm{m_{iT}} + \sigma_\mathrm{t}\mathrm{q_{iT}} \frac{\sum_{i=1}^{n} m_{iT}}{\sum_{i=1}^{n} q_{iT}} \right] \mathrm{e}^{-\mathrm{rT}} + \sum_{i=1}^{n} \varepsilon_\mathrm{iT}(\mathrm{k_{iT}} - \delta\mathrm{K_{iT}})$

Now, the REP charge will equal the refund. This can be seen from the budget constraint:

$$24)\ \mu_t \sum_{i=1}^{n} m_{it} = \sigma_t \sum_{i=1}^{n} q_{it} \frac{\sum_{i=1}^{n} m_{it}}{\sum_{i=1}^{n} q_{it}}$$

This simplifies to:

$$25)\ \mu_t = \sigma_t$$

Using 20) and 21), we can obtain an expression for the REP charge.

$$\mu_t = -\frac{(r+\delta)h_i(K_{it}) + h_i'(K_{it})\delta K_{it}}{(1-s_{it})m_{iK}}$$

Inserting this into 19) to provides the following optimality conditions:

$$26)\ \frac{\pi'_i(q_{it})}{(1-s_{it})(m_{iq}-\frac{M_t}{Q_t})} = -\frac{(r+\delta)h_i(K_{it})+h_i'(K_{it})\delta K_{it}}{(1-s_{it})m_{iK}} = \mu_t$$

An output-based REP scheme can achieve the target path of NO_X-emission reductions, but it provides non-optimal incentives for the mitigation measures. From 26), there are two factors that affect incentives that are not present in the optimality conditions for the social optimum. First, both optimality conditions in 26) are influenced by the output share of the firms (s_{it}). Second, the optimality conditions for production adjustments are affected by the difference between the firm's effect of production on emissions, compared to the average level $\left(m_{iq} - \frac{M_t}{Q_t}\right)$. I discuss these in turn.

In the special case where $s_{it} \rightarrow 1$, i.e. one firm contributes to all the output. 19) then collapses to $\pi'_i(q_{it})e^{-rt} = 0$. The firm produces until marginal profit equals zero and the production level equals $\widehat{m}_i$. From 20), the firm has no incentives to invest in abatement technology. With one firm paying for all emissions and receiving all the recycled revenues there are no incentives to reduce emissions and the firm behaves as if there are no emission regulations. In the other special case, $s_{it} \rightarrow 0$, there are many firms with insignificant output shares. From 21) and 26) the incentives for investment in abatement technology will move towards the socially optimal solution. If the emissions function is separable, i.e. $\frac{\partial^2 m_{it}}{\partial K_{it} \partial q_{it}} = 0$, then the capacity of abatement technology is socially optimal if $\mu_t = \tau_t$ Since the refund is given in proportion to output, the adjustment made by the firm will be determined by the difference m_{iq} and $\frac{M_t}{Q_t}$. Then, even if no firm has significant market shares, the output-based REP scheme will still provide non-optimal incentives for production adjustments. Finally, when $0 < s_{it} < 1$, investments in abatement technology decreases in s_{it}, from 26). An increase in output share also reduces marginal profit through increased production. As shown above, when $s_{it} \to 1$, then $\pi'_i(q_{it}) \to 0$.

In addition to output shares, the difference between a firm's emission per unit of output and the average emission per unit of output also plays an important part. If $m_{iq} < \frac{M_t}{Q_t}$, then from 26), the denominator will be negative. Since $\mu_t > 0$, marginal profit must be negative as well. It is then optimal for the firm to produce at a higher level than if there were no regulations on emissions, i.e. $q^*_{it} > \hat{q}_{it}$. Conversely, if $m_{iq} > \frac{M_t}{Q_t}$, the denominator in 26) is positive and the numerator must decrease through reduced production for a given μ_t. Production will still be higher than the socially optimal level, hence $\hat{q}_{it} > q^*_{it} > q^*_{itSO.}$[12]. Finally, if $m_{iq} = \frac{M_t}{Q_t}$, the first order condition in 19) collapses to $\pi'_i(q_{it})e^{-rt} = 0$ and the firm produces until marginal profit equals zero, i.e. $q^*_{it} = \hat{q}_{it}$. Unlike the case where $s_{it} \to 1$ however, the firm invests in abatement technology, such that $K_{it} > 0$.

Summing up, marginal increase in emission from one unit increases in production is lower, equal to or larger than the average emission intensity, respectively. Also, if $0 < s_{it} < 1$, then the discussion from the case of $s_{it} = 0$ for m_{iq} - $\frac{M_t}{Q_t}$ will still hold, but in addition, if s_{it} increases, then K_{it} decreases as $m_{iK}$is constant and the production of the firm, increases as well.

In order to achieve a given mitigation target (the optimality conditions in 7)), the REP charge with output-based refunding must be higher than the standard emission tax. For simplicity, assume insignificant output shares in 26) ($s_{it} = 0$). We can then write 26) as:

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[12] q_{itSO} is the socially optimal output level from section 2.1.

$$\frac{\pi'_i(\mathrm{q_{it}}) + \sigma_t \frac{M_t}{Q_t}}{m_{iq}} = -\frac{(r+\delta)h_i(K_{it}) + h_i'(K_{it})\delta K_{it}}{m_{iK}} = \mu_t$$

The optimality condition for production adjustments is then:

$$\frac{\pi'_i(\mathrm{q_{it}})}{m_{iq}} = \mu_t - \sigma_t \frac{M_t}{m_{iq}Q_t}$$

Equalizing this with the mitigation target from 7), we obtain:

$$27)\ \tau_t = \mu_t - \sigma_t \frac{M_t}{m_{iq}Q_t}$$

The necessary REP charge will hence be higher than the standard emission tax, i.e. $\mu_t > \tau_t$. Also, the stock of abatement technology with the REP scheme is higher than the social optimum.

4. Discussion

We now look at the effects on the firm's incentives from changes in the parameters $m_{iq}, m_{iK}, h_i(K_{it})$ and $\pi_i(q_{it})$, using comparative statics. The results are summed in table 1. The results are also illustrated using a numerical model.

4.1.Comparative statics for REP scheme based on emission reductions

4.1.1. Effect of higher emission per unit of output

Define the following emission function: $m(q,K) = x(q) - y(K)$. This function is separable and additive. The second order derivatives can be either zero or strictly positive (in the model in this paper, they are zero).

A higher effect of production on emission is given by $m = \Lambda x\big(q(\Lambda)\big) - y(K)$, where Λ is a scalar. Using the optimality condition $\frac{\pi\prime(q(\Lambda))}{\Lambda x\prime(q(\Lambda))} = \tau$, take the total derivative and assume $\partial\tau = 0$ to obtain:

$$28)\ \frac{\partial q}{\partial \Lambda} = \frac{\tau x\prime}{\pi'' - \Lambda \tau x\prime\prime} < 0$$

A firm with higher emission per unit of output will reduce its production more than an otherwise identical less emitting firm when faced with a target of emission cuts. The effect on emissions, however, is ambiguous. It will depend on whether the effect of reduced production is larger or smaller than the effect of an increased emission per unit of remaining output.

The effect on emissions can then be derived:

$$29)\frac{\partial m}{\partial \Lambda} = x + \Lambda x' \frac{\partial q}{\partial \Lambda},$$

Then, $\frac{\partial \mathrm{m}}{\partial \Lambda} > 0(< 0)$ if $\mathrm{x} > (<) \Lambda \mathrm{x}' \frac{\partial \mathrm{q}}{\partial \Lambda}$. The final effect depends upon the parameter values.

4.1.2. Effect of higher abatement ability

Define $m = x(q) - \kappa y\big(K(\kappa)\big)$. Using the optimality condition $\frac{(\mathrm{r}+\delta)\mathrm{h}(\mathrm{K}(\kappa))+\mathrm{h}'\big(\mathrm{K}(\kappa)\big)\delta \mathrm{K}(\kappa)}{\kappa \mathrm{y}'\big(K(\kappa)\big)} = \tau,$ we obtain:

$$30)\frac{\partial \mathrm{K}}{\partial \kappa} = \frac{\tau \mathrm{y}'}{\big((\mathrm{r}+2\delta)\mathrm{h}'+\mathrm{h}''\delta-\tau\kappa \mathrm{y}''\big)} > 0, \text{since } \mathrm{y}'' = 0 \text{ in the model}$$

From 30), a firm with a higher ability to abate emission, invests more in technology than an otherwise identical firm with lower abatement ability. The effect on emissions is unambiguously negative.

4.1.3. Effect of higher costs of abatement technology

Define $\Phi \mathrm{h}(\mathrm{K})$, Φ, where Φ is a scalar. Following the same method as previously, we obtain:

$$31)\frac{\partial \mathrm{K}}{\partial \Phi} = \frac{(\mathrm{r}+\delta)\mathrm{h}+\mathrm{h}'\delta \mathrm{K}}{\big((\mathrm{r}+2\delta)\Phi \mathrm{h}'+\mathrm{h}''\delta \mathrm{K}-\tau \mathrm{y}''\big)} < 0, \text{since } \mathrm{y}'' = 0 \text{ in the model}$$

A firm facing higher costs of abatement technology, invests less and hence, the stock of technology is lower. With less installed abatement technology, emissions are higher.

4.1.4. Effect of higher profit per unit of production

We define $\Omega \pi'(q(\Omega))$, where Ω is a scalar, and derive:

$$32)\ \frac{\partial q}{\partial \Omega} = \frac{\pi'}{\tau x'' - \Omega \pi''} > 0$$

A firm obtaining higher profit per unit of output, has higher production than an otherwise identical firm with lower profitability. More profit result in higher production and emission

4.2.Comparative statics for REP scheme based on output

4.2.1. Effect of higher emission per unit of output

Applying the same functional forms and assumptions as in section 4.1.1. and the optimality condition $\frac{\pi'(q(\Lambda))}{(1-s)(\Lambda x' - \frac{\Lambda M}{Q})} = \mu$, we obtain:

$$33)\ \frac{\partial q}{\partial \Lambda} = \frac{(1-s)\mu\left(x' - \frac{M}{Q}\right)}{(\pi'' - (1-s)\mu\Lambda x'')}$$

Output share affect the strength of the effect in 33), but not the direction of the effect. The sign of the effect is however dependent upon whether the firm has higher or lower emission per unit of output, compared to the average level. If $x' > \frac{M}{Q}$, the numerator is positive and hence, a more emitting firm will reduce its production more than a less emitting firm. Conversely, if $x' < \frac{M}{Q}$, the numerator is negative, and the firm will increase its production. Finally, for a firm with emissions equal to the sector average, the effect from 33) is zero. This can be seen from 19), where production continues until marginal profit equals zero.

If emission per unit of output are lower than, or equal to, the average of the regulated firms, then emissions rise unambiguously. For a firm with higher emission than average, the effect can be positive or negative. This is the same result as derived in 29).

4.2.2. Effect of higher abatement ability

Using the optimality condition $\frac{(r+\delta)h(K(\kappa)) + h'(K(\kappa))\delta K(\kappa)}{(1-s)\kappa y'(K(\kappa))} = \mu$, we derive:

$$34)\ \frac{\partial K}{\partial \kappa} = \frac{\mu(1-s)y'}{(r+2\delta)h' + \delta K h'' - \mu(1-s)\kappa y''} > 0, \text{since } y'' = 0 \text{ in the model}$$

A firm with higher ability, using abatement technology invests more in technology than an otherwise identical firm with lower abatement ability. Emissions will also be lower.

4.2.3. Effect of higher costs of abatement technology

With the optimality condition $\frac{(r+\delta)\Phi h(K(\Phi))+\Phi h\prime(K(\Phi))\delta K(\Phi)}{(1-s)y'\left(K(\kappa)\right)} = \mu$, we get:

$$35)\ \frac{\partial K}{\partial \Phi} = -\frac{(r+\delta)h+h'\delta K}{(r+2\delta)\Phi h'+\Phi h''\delta K-(1-s)\mu y''} < 0, \text{since } y'' = 0 \text{ in the model}$$

A firm facing higher costs, invests less and achieve smaller emission reductions.

4.2.4. Effect of higher profit per unit of production

Finally, the effect of higher profit per unit of output is obtained by using $\frac{\Omega\pi\prime(q(\Omega))}{(1-s)(x\prime-\frac{M}{Q})} = \mu$:

$$36)\ \frac{\partial q}{\partial \Omega} = -\frac{\pi'}{\Omega\pi''-\mu(1-s)x''} > 0$$

A firm with higher profit per unit of output have higher production and hence, higher emission than a firm that earns less per unit but that is otherwise identical.

Table 1: Results from comparative statics

Scenarios	Emissions reductions REP		Output REP	
Effect of higher emission per unit of output	q’ <	• x > Λx’∂q/∂Λ → m’ > • x < Λx’∂q/∂Λ → m’ <	• x’ > M/Q → q’ < • x’ = M/Q → q’ =0 • x’ < M/Q → q’ >	• x’ > M/Q & x > Λx’∂q/∂Λ → m’ > • x’ = M/Q → m’ =0 • x’ < M/Q → m’ >
Effect of higher abatement ability	K’ >	m’ <	K’ >	m’ <
Effect of higher costs of abatement technology	K’ <	m’ >	K’ <	m’ >
Effect of higher profit per unit of production	q’ >	m’ >	q’ >	m’ >

4.3. Numerical illustrations

In this section, we examine the effect of parameter changes on incentives for production and abatement and the impact on emissions[13]. Finally, we investigate which type of firms that are

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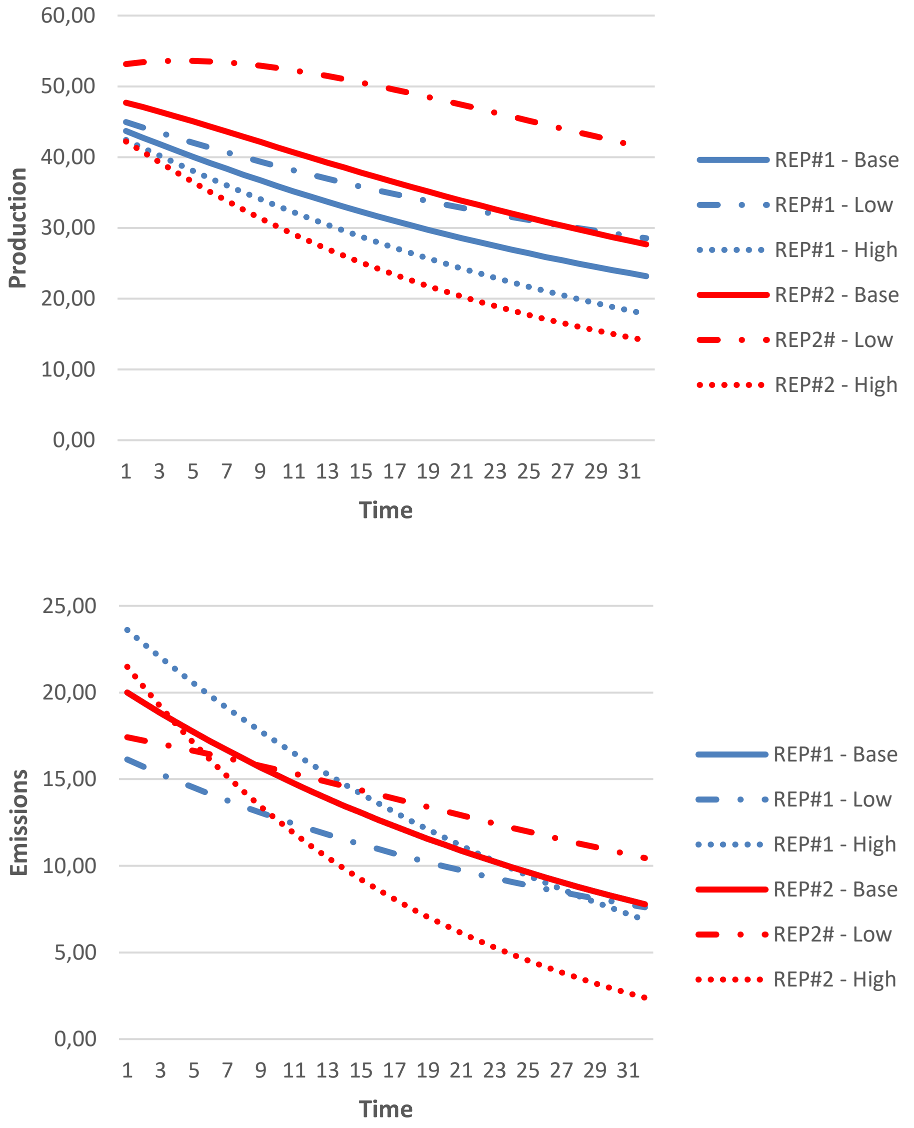
[13] The assumptions underlying the numerical illustrations, are listed in Appendix B.

winners and losers in terms of net payments under the two REP schemes. These results are summarized in Table 2.

The upper picture in Figure 2 shows the effect change in m_{iq} on production, while the lower picture shows the effect on emissions. In the “base” scenario, m_{iq} is set to 0,5 and at 0,4 and 0,6 in the “low” and “high” scenarios respectively.

Figure 2: Effect of m_{iq} on production (top) and emissions (bottom)



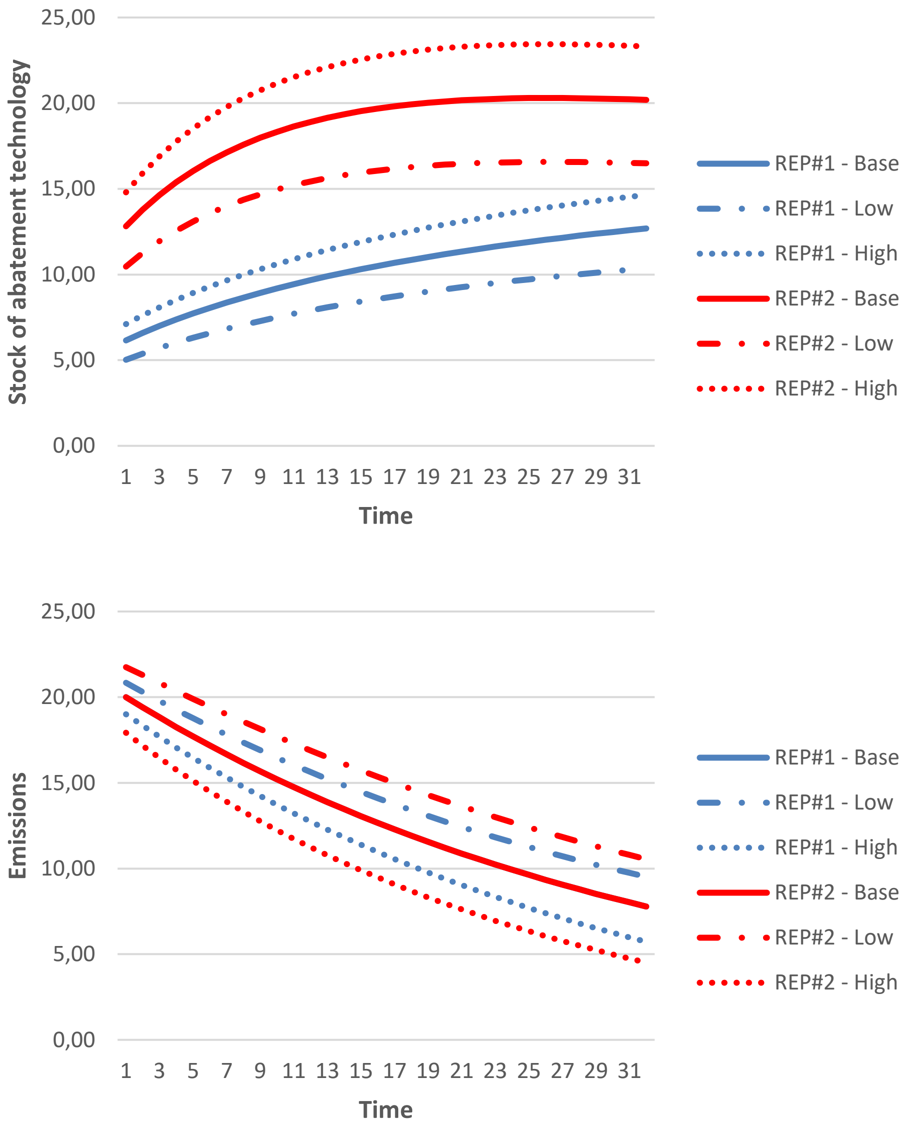
From Figure 2, under emission-reductions REP scheme (REP#1 in Figure 2, in blue), a higher emission per unit of output unambiguously results in lower output. This is also the case for the output-based REP scheme (REP#2 in Figure 2, in red), where a firm with high m_{iq}

produces less than a firm with low m_{iq}. However, production is monotonically decreasing for all firm types in the emission-reductions REP scheme. This is not the case in the output-based scheme. There, not only the level of m_{iq} matter, but also if it is higher or lower than average emission intensity. In the numerical model, this starts at 0,46 and decreases over time. The firm in both the "base" and "high" scenario is therefore above average and in accordance with the theoretical results, production decreases monotonically. In the "low" scenario however, the firm starts out as less emitting and over time becomes more emitting than average (as the average level decreases over time). The firm then starts out with increasing production, and over time decreases production. This result highlights the intent of the Swedish REP scheme. Less emitting firms are favored and can increase their production. Experience from the Swedish REP scheme also show that the average emission intensity for the regulated units decreased from 0,41 kg/MWh to 0,18 kg/MWh over the period 1992-2013. This is a reduction of 56 per cent. Total NO_x-emissions from the regulated units decreased from 15 305 tons to 13 165 tons, a reduction of 14 per cent (Naturvårdsverket, 2014, p. 25). This shows that the output-based refunding is effective at reducing the emission intensity of the regulated units.

The bottom picture of Figure 2 shows the effect of m_{iq} on emissions. A firm in the "low" scenario produces more in the output-based REP scheme and emissions are also higher. In the "high" scenario however, a firm has higher emissions in the emission-reductions scheme than under the output-based scheme even if production is lower. This is a result of the incentives for abatement technology in the output-based scheme

Figure 3 displays the effect of changes in $m_{iK.}$ In the "base" scenario, m_{iq} is 0,3, while it is set to 0,2 and 0,4 in the "low" and "high" scenarios respectively.

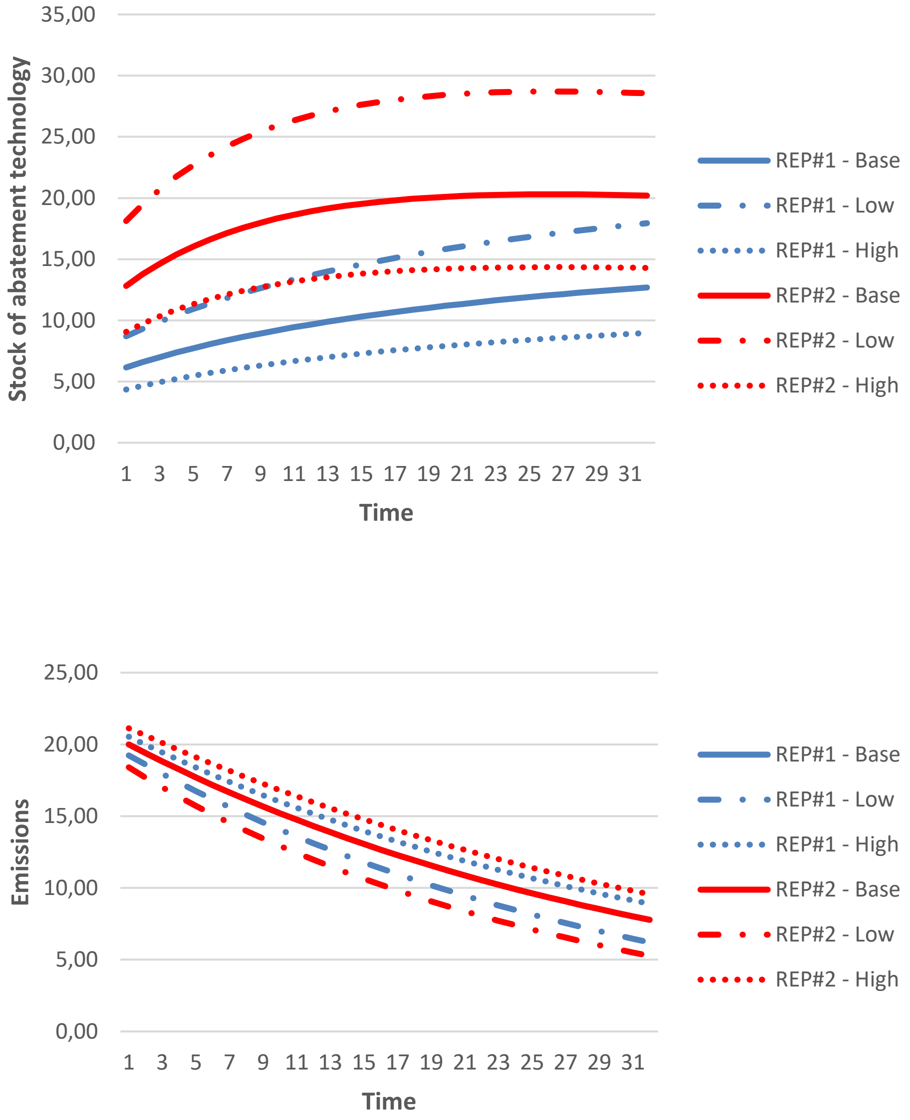
Figure 3: Effect of m_{iK} on stock of abatement technology (top) and emissions (bottom)



The results from Figure 3 show that regardless REP scheme, a higher abatement ability results in higher technology investments. Investments are also unambiguously highest under the output-based REP scheme. This is in accordance with the result derived in 27). Given the same mitigation target, the output-based scheme creates stronger incentives for investment in abatement technology. A strong incentive for adoption of abatement technologies was also an integral part of the design of the Swedish REP scheme (Bonilla et al., 2015). Even if investments in technology are higher in the output-based REP scheme, emissions are not necessarily lower. Firms with high abatement ability, emit less in the output-based scheme. However, firms with low abatement ability can emit more under the output-based scheme than under the emission-reductions REP scheme. This is a result of the output subsidy that make it profitable for a to have a higher output.

Figure 4 shows effects of changes in technology costs. In the “low” and “high” scenarios, the slope of the cost function is halved and doubled respectively.

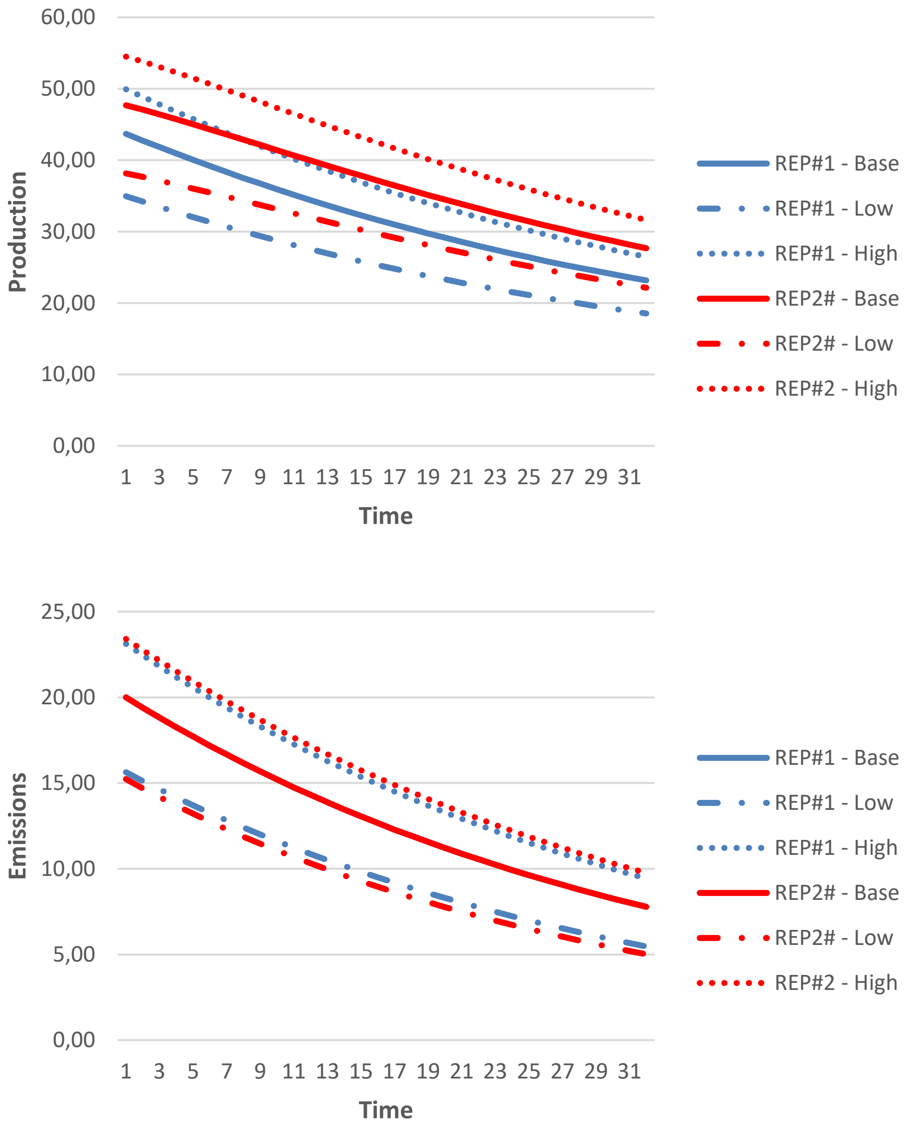
Figure 4: Effect of cost of abatement technology on stock of abatement technology (top) and emissions (bottom)



The results in Figure 4, are like those from Figure 3. A firm with low technology costs invests more, regardless of REP scheme, compared to an otherwise identical firm with higher technology costs. However, unlike the result in Figure 3, not all firm types necessarily have a higher stock of abatement technology under the output-based scheme. In terms of emissions, these are not always lower under the output-based scheme, even if abatement is generally higher. A firm with high technology costs invests more under the output-based scheme. However, emissions could also be higher since the firm also receives an output subsidy.

Figure 5 illustrates the effect of changes in the production cost function. In the “low” scenario, the slope of the cost function is halved and in the “high” scenario it is doubled.

Figure 5: Effect of profit per unit of production on production (top) and emissions (bottom)



A firm with higher profit per unit of production always produces more, regardless of REP scheme. This is in accordance with the theoretical results. The production levels are also higher for a firm in the output-based REP scheme. This is not surprising, given the output subsidy. While emissions are higher in the output-based scheme for a firm with high profit per unit of output, they may be lower for a firm with low level of profit per unit of output. This can be explained by the incentives for abatement technology in the output-based scheme.

The net payment that firms receive under the different scenarios under the two REP schemes are shown in Table 2. The net payment is the difference between the amount they pay for their emissions and the refund they receive. In the emission-reductions scheme, this is defined as $\rho_t m_{it}^* - \beta\varphi_t(\widehat{m}_i - m^*{}_{it})$ and in the output-based scheme it is $\mu_t m_{it} - \sigma_t q_{it}$.

Table 2: Net gain for different firms under the two REP schemes[14]

Scenarios	REP - emissions reductions			REP - output		
	Low	**Base**	**High**	**Low**	**Base**	**High**
Effect of emission per unit of output	-4,4	0	8	82,4	30,4	15,6
Effect of abatement ability	-6,8	0	8,1	-9,1	30,4	77,2
Effect of costs of abatement technology	6,2	0	-4,4	66,3	30,4	5
Effect of profit per unit of production	3	0	-2,1	41,7	30,4	22,4

From the first scenario, a firm with higher emission per unit of output are net-winners in the emission-reductions-based scheme. They reduce their emissions more in absolute terms and a firm with higher m_{iq} also has a higher unrestrained emission level ($\widehat{m}_i$), resulting in a higher refund. In the output-based scheme it is the opposite. As seen from Figure 3, a firm with emission per unit of output lower than the average level will also increase its output level. In both REP schemes, the net-winners in the second scenario are the firms with higher abatement ability (and hence, higher investments in technology). The effects are stronger in the output-based scheme since it induces a higher level of technology investments. The same effect is evident in the third scenario. Those who gain the most under both REP schemes are firms with lower technology costs. In the final scenario, the highest net-gain under both schemes are firms with low profit per unit of output. A firm with higher profit produces more and hence, emits more, resulting in higher payments. In the output-based scheme, the net-gains are higher, since an increased production also increases the refund.

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[14] The takeaway from Table 2 is that the level of net-gain differs across firm type under the two REP schemes. All the values are scaled down to highlight the difference in outcomes for the different firm types.

5. Summary and concluding remarks

Both REP schemes studied in the paper can achieve the target path of NOx-emission reductions announced by the regulator. The results show that is only cost-efficient when refunds are given for emission reductions. The design of the two REP schemes also target different objectives. With the emission-reductions scheme, the focus is on emission reductions and allowing regulated firms a flexible and cost-efficient way to achieve this. Since production reductions are eligible for refunds, there is not a strong incentive for upholding the activity level. In the output-based scheme however, competitive concerns are an integral part of the scheme design. Firms with lower emission per unit of output than average are favored, and these can also increase their production. Experience with the Swedish REP scheme also show that it has been successful in reducing the emission intensity of the regulated units. In addition, there are strong incentives for adoption of abatement technologies that could be beneficial for competitiveness in the long run. There are also differences concerning distribution of costs under the two REP schemes, which means that different firm types could end up as net-winners under the two REP schemes.

A REP scheme can also remedy some concerns that regulators may have about emission taxes. An advantage with an emission tax, however, is that it generates revenue. Instruments that generate revenue that can be used to reduce distortionary taxes, obtain a cost-advantage over instruments that do not (Goulder, Parry, Williams III, & Burtraw, 1999). Hence, an emission tax, even at an inefficient level, could still be appealing if revenue generation is an important concern[15]. Both REP schemes also violate the polluter-pays-principle. When refunds are given to firms that are responsible for the emissions, these firms do not fully internalize the effect of the damage they cause. Also, refunding could increase public support, but the refunding could also be perceived as unfair if the refunds are a reward for behavior that includes NOx emissions. Nevertheless, if established policy instruments prove unfeasible, a REP scheme could be an attractive addition to the regulatory toolbox.

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[15] Emission permit markets, with auctioned permits could also be used for raising-revenue, but in practice however, there may be difficulties in establishing an effective permit market as well.

Appendix

A.

The following functional forms are used in the illustrative numerical model:

$$\pi_i'(q_{it}) = A_i - q_{it}(2c_i + b_i), \quad \mathrm{h}_i(\mathrm{K}_{it}) = p_i {K_{it}}^2, \quad \mathrm{h}'_i(\mathrm{K}_{it}) = 2p_i K_{it}, \mathrm{h}''_i(\mathrm{K}_{it}) = 2p_i$$
$$\text{and } m_{it} = (\theta_i q_{it} - \alpha_i K_{it})$$

The “base” scenario uses the following parameter values:

A = 200, b =3, r = 0,05, δ = 0,05, θ = 0,5, α = 0,3, c = 0,5 and p = 2

B.

In the REP scheme based on emission reductions, the specific target path of emissions reductions is achieved when the sum of the REP charge and the refund equals the optimal emission tax (from 13)). In the output-based however, the necessary REP charge is higher than the optimal tax (from 27)).

In order to obtain the results from the numerical model, values for the “base” scenario are used to calculate the optimal emission tax, the REP charges and average emissions. These values are then saved to make them invariant to parameter changes. For the different scenarios, the parameter values for $m_{iq}, m_{iK}, h_i(K_{it})$ and $\pi_i(q_{it})$ are altered to see how different firm types act under the two REP schemes. These results are also used to calculate the net-winners and losers among firms under the different scenarios.

For the optimality conditions for the social optimum, the expressions in 7) are used. With the REP scheme based on emission reductions, the optimality conditions come from 13). For the output-based scheme, we simplify by assuming that firms have small output shares, and these are set equal to zero. This is a reasonable assumption. In 2000, the largest unit under regulation had a output share of 2,2 per cent (Sterner & Isaksson, 2006). Since then the number of units included in the REP scheme has increased. For the purpose of numerical illustration, the optimization problem for firms can be written as:

$$\max \int_0^T [\pi(q_t) - h(K_t)k_t - \mu_t m_t + \sigma_t q_t] e^{-rt}$$

The budget constraint is then:

$$\mu_t \sum_{i=1}^{n} m_{it} = \sigma_t \sum_{i=1}^{n} q_{it}$$

We can then derive the expression for the refund:

$$\sigma_t = \frac{\mu_t M_t}{Q_t}$$

The refund is now a share of the REP charge, determined by the size of the average emission per unit of output. In the theoretical model, the example where firms could differ in terms of output share, the refund equaled the REP charge (from 25)). With the assumption that the output share equals zero, the expression for the refund can be simplified. The expression above is also a good representation of how the refund is defined in the Swedish REP scheme. There, the refund is calculated as total paid charges ($\mu_t M_t$), divided by total produced energy (Q_t). The refund is also lower than the REP charge (Naturvårdsverket, 2014, p.25).

Values from the social optimum are used to calculate $\frac{M_t}{Q_t}$. The average emission per output is time-variant, and in accordance with the target path of emissions reductions it decreases over time. This corresponds with the actual development in Sweden where the average NO_x-emissions for the regulated firms have decreased over the period 1992-2013 (Naturvårdsverket, 2014, p.25-26).

With the changes made, the optimality conditions for the illustrative numerical model read:

$$\frac{\pi'_i(q_{it}) + \sigma_t}{m_{iq}} = \mu_t \rightarrow \frac{\pi'_i(q_{it})}{(m_{iq} - \frac{M_t}{Q_t})} = \mu_t$$

References

Aidt, T. S. (2010). Green taxes: Refunding rules and lobbying. *Journal of Environmental Economics and Management, 60*(1), 31-43.

Bernard, A. L., Fischer, C., & Fox, A. K. (2007). Is there a rationale for output-based rebating of environmental levies? *Resource and Energy Economics, 29*(2), 83-101.

Bonilla, J., Coria, J., Mohlin, K., & Sterner, T. (2015). Refunded emission payments and diffusion of NOx abatement technologies in Sweden. *Ecological economics, 116*, 132-145.

Bontems, P. (2019). Refunding emissions taxes: The case for a three-part policy. *The BE Journal of Economic Analysis & Policy, 19*(2).

Cato, S. (2010). Emission taxes and optimal refunding schemes with endogenous market structure. *Environmental and Resource Economics, 46*(3), 275-280.

Coria, J., & Mohlin, K. (2017). On refunding of emission taxes and technology diffusion. *Strategic Behavior and the Environment, 6*(3), 205-248.

Fischer, C. (2011). Market power and output-based refunding of environmental policy revenues. *Resource and Energy Economics, 33*(1), 212-230.

Fischer, C., & Fox, A. K. (2012). Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates. *Journal of Environmental Economics and Management, 64*(2), 199-216.

Fischer, C., Greaker, M., & Rosendahl, K. E. (2017). Robust technology policy against emission leakage: The case of upstream subsidies. *Journal of Environmental Economics and Management, 84*, 44-61.

Fredriksson, P. G., & Sterner, T. (2005). The political economy of refunded emissions payment programs. *Economics Letters, 87*(1), 113-119.

Frondel, M., Horbach, J., & Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business strategy and the environment, 16*(8), 571-584.

Gersbach, H., & Requate, T. (2004). Emission taxes and optimal refunding schemes. *Journal of Public Economics, 88*(3-4), 713-725.

Goulder, L. H., Parry, I. W., Williams III, R. C., & Burtraw, D. (1999). The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. *Journal of Public Economics, 72*(3), 329-360.

Hagem, C., Hoel, M., Holtsmark, B., & Sterner, T. (2015). *Refunding emissions payments*. Retrieved from http://www.rff.org/research/publications/refunding-emissions-payments

Hagem, C., Holtsmark, B., & Sterner, T. (2012). Mechanism design for refunding emissions payment. *Discussion Papers*(705).

Hagem, C., Holtsmark, B., & Sterner, T. (2014). Om den norske politikken for reduksjon av utslipp av NOx. *Samfunnsøkonomen*.

Johnson, K. C. (2007). Refunded emission taxes: A resolution to the cap-versus-tax dilemma for greenhouse gas regulation. *Energy Policy, 35*(5), 3115-3118.

Kallbekken, S., Kroll, S., & Cherry, T. L. (2011). Do you not like Pigou, or do you not understand him? Tax aversion and revenue recycling in the lab. *Journal of Environmental Economics and Management, 62*(1), 53-64.

Millock, K., & Nauges, C. (2006). Ex post evaluation of an earmarked tax on air pollution. *Land Economics, 82*(1), 68-84.

Millock, K., Nauges, C., & Sterner, T. (2004). Environmental taxes: a comparison of French and Swedish experience from taxes on industrial air pollution. *CESifo DICE report, 2*(1), 30-34.

Naturvärdsverket. (2014). *Ändring av kväveoxidavgiften för ökad styreffekt - Redovisning av ett regeringsuppdrag. Naturvärdsverkets rapport 6647*. Stockholm: Naturvärdsverket Retrieved from https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6647-5.pdf

NOx-avtalen 2018-2025. (2017). *Miljøavtale om reduksjon av NOx-utslipp for perioden 2018-2025* Oslo: Klima- og miljødepartementet Retrieved from file://eir.uib.no/home7/ahe068/Downloads/nox-avtalen-2018-2025-signert.pdf

NOx-fondet. (2018). *Årsrapport 2017: Rapport om oppfyllelse av reduksjonsforpliktelsene for 2017 i henhold til Miljøavtalen om NOx 2011-2017*. Retrieved from https://www.nho.no/siteassets/nox-fondet/rapporter/2018/nox-fondet-arsrapport-2017_oppslag.pdf

NOx-fondet. (2019). *Veiledning: Søknad om støtte under NOx-avtalen 2018-2025, version 2.0*. Retrieved from https://www.nho.no/siteassets/nox-fondet/soknader-og-egenerklaringer/nox_veiledning-versjon-2.0-2019-18-september.pdf

Pinchasik, D. R., & Hovi, I. B. (2017). A CO2-fund for the transport industry: The case of Norway. *Transport Policy, 53*, 186-195.

St.prp. nr. 1 (2006-2007). (2006). *For budsjettåret 2007 Skatte-, avgifts- og tollvedtak*. Oslo: Finansdepartementet Retrieved from https://www.regjeringen.no/no/dokumenter/stprp-nr-1-2006-2007--3/id298027/sec3

Sterner, T., & Isaksson, L. H. (2006). Refunded emission payments theory, distribution of costs, and Swedish experience of NOx abatement. *Ecological economics, 57*(1), 93-106.

Sterner, T., & Turnheim, B. (2009). Innovation and diffusion of environmental technology: Industrial NOx abatement in Sweden under refunded emission payments. *Ecological economics, 68*(12), 2996-3006.

Institutt for økonomi
Universitetet i Bergen
Postboks 7800
5020 Bergen
Besøksadresse: Fosswinckels gate 14
Telefon: +47 5558 9200
Fax: +47 5558 9210
www.uib.no/econ/