Fondazione Eni Enrico Mattei

The Combined Use of Taxation and Voluntary Agreements for Energy Policy

Katrin Millock

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Corso Magenta, 63, 20123 Milano, tel. +39/02/52036934 – fax +39/02/52036946
E-mail: letter@feem.it
C.F. 97080600154

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Katrin Millock, Ph.D.
Centre International de Recherche sur l'Environnement et le Développement
(CIRED), EHESS-CNRS
45 bis, avenue de la Belle Gabrielle
94 736 Nogent sur Marne Cedex
France

millock@centre-cired.fr

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1. Introduction

Denmark introduced a carbon tax unilaterally in 1993. Currently, energy-intensive industry may opt out of the standard tax policy by signing a voluntary agreement with the Danish Energy Agency. The voluntary agreement comprises an energy audit that determines a set of investments to be undertaken by the firm. In return, the firm pays a lower unit tax rate on carbon emissions. The policy was designed to bolster the effects of a unilateral tax on international competitiveness. It is well known that a tax exemption of energy-intensive industry is an inefficient method to deal with the concerns about international competitiveness. Hoel (1996) has shown that it is only when border taxes cannot be applied that such a policy may be second-best. Thus, the tied-hands of the regulator can explain why an otherwise sub-optimal policy may be adopted. This paper aims at analysing another reason for partial exemption of some industries from carbon taxation, namely asymmetric information. The paper shows how the combined use of emission taxation and voluntary agreements can work as a mechanism to deal with the problem of asymmetric information between the regulator and industry on effective energy use. The model incorporates some critical features of the Danish voluntary agreement:

1) The regulator does not know the special characteristics of the firm's production process and efficiency of input use;
2) The regulator offers a policy into which firms self-select according to type, e.g. either pay the standard carbon tax or sign a voluntary agreement;
3) The cost of audits is borne by the individual firm;
4) Initial empirical evidence point to systematic factors determining which firms opt for an energy audit.

In addition, energy use and emissions cannot easily be inferred from production data since companies have private knowledge of production processes and related energy use. CO_2 emissions from the cement sector, for example, are not the same for a given level of input use since the efficiency of the production process differs between firms. It is important that the analysis accounts for this link.

The model suggested here is based on asymmetric information. It assumes that the firm has private knowledge about its production process and energy use. By incurring the cost of the energy audit specified in the Danish agreement, the firm and the regulator may discover opportunities for energy efficiency investments. This is captured in the model by allowing for a change in energy consumption, and profits, with and without an audit, all else equal.

The paper is structured in the following manner. First, relevant features of the Danish Agreements on Energy Efficiency are presented in Section 2. Next, in Section 3, the basic model is outlined. Section 4 determines the benchmark first-best allocation under full information, whereas Section 5 then studies optimal allocation of energy use under asymmetric information and costly monitoring. Section 6 compares the results with the policy of the Danish Agreements. Section 7 concludes and suggests some extensions of the current work.

2. The Danish agreements on energy efficiency

Denmark introduced a CO_2 tax on industry in 1993. A tax on SO_2 emissions was later introduced in combination with increases in the CO_2 tax. The level of the CO_2 tax varies depending on industry branch and type of industrial process, with space heating carrying the highest tax rate, and light and heavy processes a lower tax rate. Only energy-intensive companies can enter into a voluntary agreement. Firms using heavy processes are automatically defined as energy-intensive. Such processes account for 61% of all energy use in industry (Togeby, Bjørner and Johannsen, 1998). Companies with light processes are defined as energy-intensive if the yearly tax payments on their energy use amounts to at least 3 per cent of their value added. Before the agreement is signed an energy audit should be performed and an energy plan elaborated. From 1997 all energy audits have to be verified by an independent consultant. The cost of verification is borne by the company, which commits to implementing a list of investments in energy efficiency identified in the audit according to a payback criterion of 4-6 years. In return, the firm obtains a reduction in the CO_2 tax. For example, in the absence of an agreement, heavy processes carry a tax of 25 DKK per tonne of CO_2. With an agreement, it can be reduced to 3 DKK per tonne CO_2 , equivalent to a reduction from approximately 3.4 to 0.4 USD/tonne CO_2 (Togeby, Bjørner and Johannsen, 1998).

The energy audit is performed by a consultant certified by the Energy Agency. Evaluations of the energy agreement show that the Agency is totally dependent on the information obtained in the audit - that is, companies possess private information and the only source of learning that information is through the energy audit (Krarup, Togeby and Johannsen, 1997). The company itself monitors the progress of the investments and should report regularly to the regulator. If the regulator cannot accept the energy progress report, it may require repayment of the CO_2 tax rebate and discontinue the agreement.

The maximum length of an agreement is 3 years. From 1996 to 1998, agreements were concluded with 300 individual companies and 100 greenhouses. (Energistyrelsen, 1999).[1] In 1996, 30 companies entered into energy agreements, representing 32% of industry energy consumption. Three companies contributed 58% of the energy consumption, and the savings predicted from the agreement also differed largely between companies (Krarup, Togeby and Johannsen, 1997). There is thus significant heterogeneity in industry energy use. A large part of the energy savings would have been implemented without agreements (Krarup, Togeby and Johannsen, 1997).

While it is still quite early for evaluations of the Danish voluntary agreements, some initial evaluations have been performed. The most recent evaluation of the agreements was based on phone interviews with energy managers from 150 large companies, and found on average a 1.4% energy savings due to the agreement, adjusted for 'baseline' savings (under the 3 years of the agreement). Most of the firms were one year into the agreement when surveyed. Total expected energy savings were 2.2%, including investments made without the agreement (Togeby and Hansen, 1998). The Danish Energy Agency predicts CO_2 reductions of 2.7 % by 1999, and a 6.3 % reduction from the continuation of the agreements to 2005 (Energistyrelsen, 1999).

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[1] In the description, we abstract from an early trial period in 1993-95 in which energy-intensive companies were exempt from the CO_2 tax under similar conditions as today's formal energy agreements.

Jensen (1998) uses a static computable general equilibrium model in order to numerically compare the costs of a carbon tax exemption for energy-intensive industry with a system of grand-fathered tradeable emission permits. For a given reduction target of -20% of baseline CO_2 emissions, a carbon tax exemption results in a higher welfare loss than a system under which energy-intensive industry is assisted through grand-fathered emission permits. Given the estimated cost of a partial exemption of industry from a carbon tax, it is important to understand its potential justification in terms of costly and asymmetric information. Section 3 outlines a basic model of heterogeneity and energy use under which the regulator can save on information rents through the combined use of emission taxation and a voluntary agreement.

3. The model

The model is based on a vintage view of technology similar in spirit to the model of endogenous monitoring proposed in Millock (1998). Each firm is characterized by a productivity parameter θ, taken to represent heterogeneity in the efficiency of input use across firms. θ can be interpreted as an index encompassing different factors such as the vintage of technology and the quality of management. The regulator does not know individual values of θ, only its distribution on a support $[\underline{\theta}, \bar{\theta}]$ with a known, continuous, strictly positive density function $f(\theta)$ and a distribution function $F(\theta)$. We also make the assumption that $\frac{[1-F(\theta)]}{f(\theta)}$ is non-decreasing in θ.

The firm's energy use is dependent on its technology and production process. Denoting energy use e, we have $e=e(\theta)$. The net profits derived from an individual firm are denoted $\pi(e,\theta)$, where $\pi(e,\theta)$ is shorthand notation for the full specification of the value of output net of input costs: $p_y g(e(\theta),\theta) - p_e e(\theta)$. Output price p_y and energy price p_e are assumed exogenous. The production function g is concave in energy use e and increasing in θ:

$$\frac{\partial g}{\partial e} > 0; \frac{\partial^2 g}{\partial e^2} \leq 0; \frac{\partial g}{\partial \theta} > 0; \frac{\partial^2 g}{\partial \theta^2} \geq 0; \frac{\partial^2 g}{\partial e \partial \theta} < 0.$$[2]

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[2] Third derivatives assumed zero.

One important feature of the model is that the negative externalities from energy use are modelled separately as depending on the efficiency with which energy is used, as well as on the absolute level of energy use. That is, emission factors per input are not constant across firms. In fact, different production processes, management and maintenance of equipment create different levels of emissions. This is the most evident for emissions of particulate matter or sulphur dioxide, but also for carbon emissions heterogeneity among firms affects emissions. Khanna and Zilberman (1997) document several production processes for which this is the case. In the cement industry, for example, the use of a dry process versus a wet process can significantly change both firm profits and the resulting level of carbon emissions. Indeed, we will see that this modelling feature will be crucial in analysing the economic efficiency of policy. By incurring transaction costs to negotiate a voluntary agreement, the regulator will be able to target emissions more directly according to each firm's specific emissions rather than base taxation on average values expressed in standard emission factors.

The negative externalities from energy use, z, thus depend upon 'applied' energy, e, and the vintage efficiency parameter θ: $z = z(e(\theta),\theta)$:

$$\frac{\partial z}{\partial \theta} < 0; \quad \frac{\partial z}{\partial e} > 0; \quad \frac{\partial^2 z}{\partial e^2} \geq 0 .$$

Higher θ implies less pollution, and the pollution production function is convex in energy use.

The voluntary agreement entails that the firm undertakes an energy audit and implements the recommendations concerning energy savings suggested by the audit. The firm pays for the audit[3]. Given heterogeneity among firms, in addition to the fact that an energy audit is costly, the policy will result in a partitioning of firms into two groups, one that agrees to the energy audit regulation, $\theta \in \Theta_1$, and one group that does not, $\theta \in \Theta_0$.

Energy use for a firm θ with a voluntary agreement is defined as $e_1(\theta)$, whereas energy use of firms choosing not to reveal information to the regulator is denoted $e_0(\theta)$. Given that a firm that commits to a voluntary agreement has to undertake certain energy efficiency investments, profits for such firms, all else equal, are assumed to be lower: $\pi_1(\theta) < \pi_0(\theta)$. $\pi_0(\theta)$ thus represents status quo profits, excluding any energy tax payments, whereas $\pi_1(\theta)$ defines profits constrained to the requirements of the voluntary agreement.

Energy use, and thus pollution, will differ between the two groups, and expected aggregate pollution can be written as

$$Z = \int_{\Theta_0} z(e_0(\theta),\theta) f(\theta) d\theta + \int_{\Theta_1} z(e_1(\theta),\theta) f(\theta) d\theta \tag{1}$$

Aggregate private surplus and energy use are similarly defined:

$$\Pi = \int_{\Theta_0} \pi_0(e_0(\theta),\theta) f(\theta) d\theta + \int_{\Theta_1} \pi_1(e_1(\theta),\theta) f(\theta) d\theta \tag{2}$$

$$E = \int_{\Theta_0} e_0(\theta) f(\theta) d\theta + \int_{\Theta_1} e_1(\theta) f(\theta) d\theta \tag{3}$$

The objective of the regulator is to maximize aggregate net profits from production less the environmental damage costs from energy use C(Z). The damage function C(·) is assumed to be convex in aggregate pollution. Note that we make the common, but sometimes unrealistic assumption that the marginal damage cost is known in order to concentrate on the main issue at hand here: energy audits and emission taxation. Furthermore, energy is treated as one input, of which the externality and efficient use only depends upon the production process of the firm. Negative externalities vary between different fuel sources, so this obviously detracts from reality. Nevertheless, a model of one energy input is a first step.

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[3] It is straightforward to introduce possible subsidies towards the audit cost, but it does not change the main result.

4. Full information first-best energy use

As a benchmark, consider the situation with full information. A benevolent regulator would want to maximize the social surplus derived from energy use net of its environmental costs:

$$\underset{e(\theta)}{Max} \quad \int_{\underline{\theta}}^{\bar{\theta}} [\pi(e(\theta),\theta)] f(\theta) d\theta - C\left[\int_{\underline{\theta}}^{\bar{\theta}} z(e(\theta),\theta) f(\theta) d\theta \right].$$

In equilibrium, optimal full information energy use, e^*, is characterized by:

$$\frac{\partial \pi(e^*(\theta),\theta)}{\partial e} = C'(Z) \frac{\partial z(e^*(\theta),\theta)}{\partial e} \qquad \forall \theta . \tag{4}$$

Optimal energy use is at the level where the marginal product of energy equals its full social marginal cost.[4] When information is freely available, the optimal policy is a Pigovian tax on emissions. If social damage costs of aggregate pollution can be measured, optimal input use can be implemented by setting a charge t per unit pollution equal to C'(Z). Each firm then solves

$$\underset{e}{Max} \quad \pi(e(\theta),\theta) - tz(e(\theta),\theta)$$

and sets energy use at

$$\frac{\partial \pi(e^*(\theta),\theta)}{\partial e} = t \frac{\partial z(e^*(\theta),\theta)}{\partial e} . \tag{5}$$

Totally differentiating (5) shows that the signs of $\frac{\mathrm{d}e^*}{\mathrm{d}\theta}$ and $\frac{\mathrm{d}z^*}{\mathrm{d}\theta}$ are determined by the sign of $\frac{\partial^2 \pi}{\partial e \partial \theta}$ and $\frac{\partial^2 z}{\partial e \partial \theta}$.[5] If $\frac{\partial^2 \pi}{\partial e \partial \theta} > 0$ (<0) and $\frac{\partial^2 z}{\partial e \partial \theta} < 0$ (≥0), then $\frac{\mathrm{d}e^*}{\mathrm{d}\theta} > 0$ (<0).

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[4] The second order condition holds because of the assumptions of a concave profit function and a pollution production function that is convex in input use.

[5] Detailed derivation in Appendix.

Since $\frac{d\,z^*(e^*(\theta),\theta)}{d\theta}=\frac{\partial z}{\partial\theta}+\frac{\partial z}{\partial e}\frac{d e^*}{d\theta}$, $\frac{d\,z^*(e^*(\theta),\theta)}{d\theta}$ is negative when $\frac{d\,e^*(\theta)}{d\theta}$ is negative, or, when $\frac{d\,e^*(\theta)}{d\theta}$ is positive but not so large as to outweigh the direct effect from $\frac{\partial z}{\partial\theta}$. We will retain the case where $\frac{d\,e^*(\theta)}{d\theta}$ < 0 and energy use decreases with θ.[6] Given the definition of $\frac{d\,z^*(e^*(\theta),\theta)}{d\theta}$, pollution then decreases with θ.

Some firms will exit following the imposition of an emissions charge. Given our assumptions, profits increase with θ ($\frac{d\pi}{d\theta}=\frac{\partial g}{\partial\theta}-t\frac{\partial z}{\partial\theta}>0$), and the marginal unit of production, θ_m, is defined by

$$p_y g(e(\theta_m),\theta_m)-p_e e(\theta_m)-tz(e(\theta_m),\theta_m)=0\,. \tag{6}$$

Remaining firms are $\theta\in\left[\theta_m,\bar{\theta}\right]$.

5. Energy audits under incomplete and costly information

Now, we proceed to the actual case of costly and asymmetric information. Following Laffont and Tirole (1993) we use the Revelation Principle to derive optimal policy. In order to elicit information on actual energy use, and implicitly, actual carbon emissions, the regulator uses a mechanism under which the agent reveals θ and agrees to a contract with the regulator that specifies the level of energy to be used, e(θ), and a tax payment T(θ). Some firms will choose to sign a voluntary agreement and some will prefer to pay the standard emission tax and not reveal information to the regulator.

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[6] This holds under the assumption that $\frac{\partial^2 g}{\partial e\partial\theta}$<0 and $\frac{\partial^2 z}{\partial e\partial\theta}$ ≥ 0.

The setting of the model is the following. The firm knows θ and its energy use. At time t, the regulator offers a contract $e(\hat{\theta}), T(\hat{\theta})$ based on the firm's announcement of θ: $\hat{\theta}$. The firm accepts or not. If a voluntary agreement is chosen, an energy audit is undertaken at cost v. At time t+1, the firm generates pollution z(e(θ),θ) and net profits π(e(θ),θ) and is taxed according to contract T(θ).

Since both production and pollution are determined by energy use in combination with the heterogeneity parameter, it is enough for the regulator to determine energy use of the firms and the cut-off θ_c that separates firms that sign a voluntary agreement from those that opt to pay the standard carbon tax.

The individual firm has utility $U(\theta,\hat{\theta}) = \pi(e(\hat{\theta}),\theta) - T(\hat{\theta})$. Given costly monitoring, the optimal solution will allocate firms into at most two groups, one for which a voluntary agreement is signed involving costly auditing, $\theta \in \Theta_1$, and one group that pays the standard carbon tax, $\theta \in \Theta_0$.

Taking into account the cost of public funds, λ, the regulator's social welfare maximization problem is:

$$\underset{e(\theta),\Theta_0,\Theta_1}{Max} \int_{\Theta_0} \{\pi_0(e_0(\theta),\theta) - \frac{\lambda}{1+\lambda}U(\theta)\} f(\theta)d\theta + \int_{\Theta_1} \{\pi_1(e_1(\theta),\theta) - v - \frac{\lambda}{1+\lambda}U(\theta)\} f(\theta)d\theta -$$

$$-\frac{1}{1+\lambda}C[\int_{\Theta_0} z(e_0(\theta),\theta)f(\theta)d\theta + \int_{\Theta_1} z(e_1(\theta),\theta)f(\theta)d\theta\ ].$$

subject to the participation constraint

$$U(e(\theta),\theta) \geq \underline{U} = 0 \qquad \forall\theta \qquad \text{(IR)}$$

and the individual incentive compatibility constraints

$$U(e_0(\theta),\theta) \geq U(e_1(\theta),\theta) \qquad \forall\theta \in \Theta_0 \qquad \text{(IC}_0\text{)}$$

$$U(e_1(\theta),\theta) \geq U(e_0(\theta),\theta) \qquad \forall \theta \in \Theta_1 \qquad \text{(IC}_1\text{)}$$

Reservation utility, $\underline{\text{U}}$, is normalized to zero. The first order condition for incentive compatibility can be written as

$$p_y \frac{\partial g}{\partial e}\frac{de}{d\theta} - \frac{dT}{d\theta} = 0 .$$

By assumption, $\frac{\partial^2 g}{\partial e \partial \theta} < 0$, and so, energy use decreases with θ ($\frac{d\,e}{d\,\theta} < 0$), and $\frac{\text{d}\,\text{T}}{\text{d}\,\theta} < 0$ (high θ implies less pollution).

The local second order condition reads

$$\frac{\partial^2 g}{\partial e \partial \theta}\frac{de}{d\theta} \geq 0 .$$

A sufficient condition that guarantees incentive-compatibility is thus $\frac{\partial^2 g}{\partial e \partial \theta} < 0$ and $\frac{\partial^2 z}{\partial e \partial \theta} \geq 0$ (then, $\frac{d\,e}{d\,\theta} < 0$).

Using the Envelope Theorem, the growth in information rents to truth-telling firms is $\dot{U} = p_y \frac{\partial g}{\partial \theta} > 0$. Since rents are costly to the regulator and increase with θ, the IR constraint binds only at $\underline{\theta}$:

$$U(e(\underline{\theta}),\underline{\theta}) = 0 . \qquad \text{(IR')}$$

Using (IR') and integrating by parts yields

$$\int_{\underline{\theta}}^{\theta} U(\theta) f(\tilde{\theta}) d\tilde{\theta} = \int_{\underline{\theta}}^{\theta} [1 - F(\tilde{\theta})] \frac{\partial \pi}{\partial \tilde{\theta}} d\tilde{\theta} .$$

Since audited firms do not receive any information rents, the maximization problem can then be rewritten as follows:

$$
\underset{e(\theta),\theta_c}{Max} \int_{\underline{\theta}}^{\theta_c} \{\pi_0(e_0(\theta),\theta) - \frac{\lambda}{1+\lambda}\frac{[1-F(\theta)]}{f(\theta)}\frac{\partial \pi}{\partial \theta}\} f(\theta)d\theta + \int_{\theta_c}^{\bar{\theta}} \{\pi_1(e_1(\theta),\theta) - v\} f(\theta)d\theta -
$$

$$
-\frac{1}{1+\lambda} C[\int_{\underline{\theta}}^{\theta_c} z(e_0(\theta),\theta)f(\theta)d\theta + \int_{\theta_c}^{\bar{\theta}} z(e_1(\theta),\theta)f(\theta)d\theta\ ].
$$

Given the model's assumptions the program is concave in θ_c and in $e(\theta)$. In order to find the cut-off level at which a firm is indifferent between signing a voluntary agreement and paying an emissions tax, we impose two conditions that guarantee an interior solution:

$$
\begin{aligned}
&\pi(\mathrm{e}_0(\bar{\theta}),\bar{\theta}) - \frac{\lambda}{1+\lambda}\frac{[1-F(\bar{\theta})]}{f(\bar{\theta})}\frac{\partial \pi}{\partial \theta} - \pi(\mathrm{e}_1(\bar{\theta}),\bar{\theta}) + \mathrm{v}\ - \\
&-\frac{1}{1+\lambda}\mathrm{C}'[\mathrm{z}(\mathrm{e}_0(\bar{\theta}),\bar{\theta}) - \mathrm{z}(\mathrm{e}_1(\bar{\theta}),\bar{\theta})] < 0 \quad ;
\end{aligned} \tag{7}
$$

and

$$
\begin{aligned}
&\pi(e_0(\underline{\theta}),\underline{\theta}) - \frac{\lambda}{1+\lambda}\frac{[1-F(\underline{\theta})]}{f(\underline{\theta})}\frac{\partial \pi}{\partial \theta} - \pi(e_1(\underline{\theta}),\underline{\theta}) + v - \\
&-\frac{1}{1+\lambda}C'[z(e_0(\underline{\theta}),\underline{\theta}) - z(e_1(\underline{\theta}),\underline{\theta})] > 0\,.
\end{aligned} \tag{8}
$$

If (7) is not satisfied, the cost of auditing is not balanced by its benefits in terms of reduced energy use and so, no energy audits should be undertaken. Equation (8) rules out the case where the benefits from auditing are so large, or the cost from the energy audit so small that all firms should sign a voluntary agreement. The regulator's objective is a continuous function and thus, given that equations (7) and (8) hold, we have an interior solution for which the optimal cut-off level is characterized by equation (9):

$$
\pi(e_0(\theta_c),\theta_c) - \pi(e_1(\theta_c),\theta_c) + v = \frac{\lambda}{1+\lambda}\frac{[1-F(\theta_c)]}{f(\theta_c)}\frac{\partial \pi}{\partial \theta} + \frac{1}{1+\lambda}C'(Z)\left[z(e_0(\theta_c),\theta_c) - z(e_1(\theta_c),\theta_c)\right] \tag{9}
$$

The left-hand side of equation (9) represents the cost of an energy audit, v, adjusted for the private profit differential arising from a change in energy use following the voluntary agreement, whereas the right hand side measures the benefits of auditing firms in terms of reduced environmental damage and saved information rents. The intuition is then clear: on the margin, the cost of an energy audit has to balance the costly information rents for firms who choose not to reveal their private information on productivity. The audit cost modelled here could be interpreted as transaction costs in a wider sense. Evaluations of the Danish energy agreements found that the administrative costs due to energy audits and verifications were quite substantial: between 10 and 20 per cent of the tax subsidy (Energistyrelsen, 1999). The current model proposes a view of voluntary agreements as a trade-off between such costs and the potential benefits in terms of saved information rents and environmental gains from adjusted pollution levels. Comparative statics on equation (9) show that the proportion of firms that should sign a voluntary agreement varies directly with the environmental damage cost - C'(Z) – and with the responsiveness in the profit and pollution functions, but inversely with the fixed cost of monitoring. We can now fully characterize the optimal solution under costly information:

<u>Proposition 1</u>:

There exists an optimal cutoff level θ_c, above which firms sign a voluntary agreement, and below which firms choose to pay a standard emission tax.

a) θ_c is given by

$$\pi(e_0(\theta_c),\theta_c) - \pi(e_1(\theta_c),\theta_c) + v = \frac{\lambda}{1+\lambda}\frac{[1-F(\theta_c)]}{f(\theta_c)}\frac{\partial \pi}{\partial \theta} + \frac{1}{1+\lambda}C'(Z)\left[z(e_0(\theta_c),\theta_c) - z(e_1(\theta_c),\theta_c)\right]$$

b) For $\theta \in [\underline{\theta}, \theta_c[$ energy use $e_0(\theta)$ should verify

$$\frac{\partial \pi_0}{\partial e_0} - \frac{\lambda}{1+\lambda}\frac{[1-F(\theta)]}{f(\theta)}\frac{\partial^2 \pi}{\partial \theta \partial e_0} - \frac{1}{1+\lambda}C'(Z)\frac{\partial z}{\partial e_0} = 0 \qquad (10a)$$

c) For $\theta \in [\theta_c, \bar{\theta}]$, energy use $e_1(\theta)$ verifies

$$\frac{\partial \pi_1}{\partial e_1} - \frac{1}{1+\lambda}C'(Z)\frac{\partial z}{\partial e_1} = 0 \qquad (10b)$$

Firms at the higher end of θ should after revealing their efficiency parameter use energy at a socially efficient level (10b). Firms that choose not to reveal their private information about productivity will use energy at a level higher than optimal (10a). Note that proposition 1b) only defines the optimal allocation of energy use for those firms and not its implementation. Whether the individually specific level of energy use could be implemented by a linear emission tax is another matter.

6. Discussion

While the normative analysis in Section 5 identified optimal allocation under costly information, what can be predicted about the results of the Danish policy? First, note that comparative statics show that the costlier the audit, the smaller proportion of firms should sign an agreement. In addition, the optimal level of firms signing an agreement depends upon the gain from targeting policy to obtain an emission level $z(e_1(\theta),\theta)$ rather than $z(e_0(\theta),\theta)$. The gain from information about the individual production parameters will be larger for some emissions than for others. For certain processes, carbon emissions may be approximately proportional to input use, since there are no end-of-pipe abatement measures that can reduce emissions. In that case, the gains from obtaining more detailed information on individual plant characteristics and emissions are low, and may not offset the transaction costs of negotiating a voluntary agreement. The model thus suggests that the information gained from a voluntary agreement could be used to calibrate tax payments according to effective energy use and emissions, instead of basing tax payments on standard emission factors from input. The gains from doing so are large for some forms of emissions, such as sulphur emissions or particulate matter. Even for carbon-emitting industrial processes, the variation in emissions across firms is not fully reflected in emission factors. On the other hand, the information rationale for signing voluntary agreements for carbon emissions is a priori low. Instead, it is more likely that the benefits from such agreements are obtained from their use on other pollutants, where the information gains may balance the cost of the implementation of a voluntary agreement.

Let us now adapt the model results slightly to better reflect the Danish policy, which entails only a partial reduction of the emission tax. Each firm compares profits under the two options (standard carbon tax or voluntary agreement). The difference in profits between signing the voluntary agreement and paying the standard emission tax is defined as $\Delta\pi(\theta) = \pi_1(\theta) - \pi_0(\theta)$. A switch point θ_c is defined implicitly by the point where a firm is indifferent between the two options: $\pi_1(\theta_c) = \pi_0(\theta_c)$ or $\Delta\pi(\theta_c)=0$. The following conditions characterize an equilibrium under the Danish policy:

Proposition 2:

a) If $\frac{\partial^2 g(e,\theta)}{\partial e \partial \theta} < 0$, the profits from signing a voluntary agreement increase with θ.

b) If the distribution of θ is such that $\Delta\pi(\underline{\theta}) < 0$; $\Delta\pi(\overline{\theta}) > 0$, and since $\Delta\pi(\theta)$ is a continuous function, there exists one θ that separates firms into two groups, one that signs a voluntary agreement and one that chooses to pay the standard carbon tax .

c) Given a standard carbon tax rate = t_0 and a reduced carbon tax rate = t_1, the cut-off level θ_c above which polluters will sign a voluntary agreement is characterized by

$$\Delta\pi(\theta_c) - t_1 z(e_1(\theta_c), \theta_c) + t_0 z_0(e_0(\theta_c), \theta_c) - v = 0$$

where $\Delta\pi = \pi(e_1(\theta_c), \theta_c) - \pi(e_0(\theta_c), \theta_c)$

d) The condition $\pi(\theta_m)=0$ defines the lower bound of θ for production. Since profits increase in θ, production units with $\theta \in [\underline{\theta}, \theta_m]$ exit the market.

Proposition 2 implicitly defines the switch level, θ_c , as a function of the emission tax rate t_0, as well as the reduced emission tax rate t_1, the profit differential between the two options, and the cost of the energy audit, v. The regulator can thus affect the proportion of firms that sign a voluntary agreement, that is, change θ_c, by changing the tax rates and the cost of energy audits. For example, a larger carbon tax reduction (t_0-

t_1) or a decrease in the cost of an energy audit will increase the proportion of polluters that sign a voluntary agreement (that is decrease θ_c).

Proposition 2 shows that the characteristics of the production function play an important role in determining which firms will choose to sign an agreement. In fact, if the responsiveness of the firm's pollution level is small, it is less likely that using a voluntary agreement would be socially optimal.

We can now sum up the main results of the analysis:

1. When audit costs are sufficiently large (in the sense defined by equation 7), it is not in the regulator's interest to implement compulsory energy audits for all firms.
2. The Danish voluntary agreement could then be a useful method to have firms self-select into the energy audit scheme. The paper shows that under certain conditions (negative correlation between output and pollution), an incentive-compatible equilibrium exists under which some firms opt for a voluntary agreement and some choose to pay the standard carbon tax. However, the gains from using a voluntary agreement derive mainly from the possibility of close targeting of policy, which suggests that its use is more relevant for other pollutants than carbon emissions. The transaction costs expended in relation with the Danish energy agreements may not be counterbalanced by the information gains.
3. The regulator's view on the correlation between energy use and the negative externalities that it creates is crucial. If energy use is at the level where $\frac{\partial^2 g}{\partial e \partial \theta} < 0$ holds, firms signing a voluntary agreement are already energy efficient, but also more productive firms, which may justify a reduced carbon tax rate on such firms. It could also be taken as a corroboration of the suspicion that a large part of the energy savings under a voluntary agreement would have been implemented anyway. If, on the other hand, the opposite holds ($\frac{\partial^2 g}{\partial e \partial \theta} > 0$), then the proposed policy involves subsidizing heavy energy users, which are the units supposed to be targeted by an emissions tax. The policy would then imply a partial exemption of such firms from a necessary restructuring. The Danish Energy Agency indeed

clearly states that the reason for introducing the energy agreements was to limit any negative effects on competitiveness. What we have done here is to raise some cautionary arguments regarding their use.

7. Conclusion

The analysis has shown how allowing for firm 'opt-out' of a taxation scheme may save on information costs under asymmetric information and thus explain a policy that otherwise would not be first-best. We obtained conditions that determine the characteristics of the firms choosing to sign a voluntary agreement and the impact of different parameters on the equilibrium. The model proposes a view of voluntary agreements as a trade-off between transaction costs and the better targeting of policy. By signing a voluntary agreement the regulatory agency incurs significant costs of negotiation. On the other hand, the more detailed information obtained from a voluntary agreement could be used to adjust policy, permitting more cost-effective emission reductions by the targeting of policy. Compared to actual Danish policy, this suggests a role for incorporating all emissions into the agreement. Using voluntary agreements solely for carbon emissions cannot be justified according to the framework of asymmetric information studied here. Further modelling of the fear of carbon leakage is necessary in order to justify current policy (see for instance Chidiak, 1999).

Several extensions of the model seem relevant. First, modelling the dynamics of the current policy is important. The voluntary agreements on energy that Danish industry may sign are normally for a three year period, after which they have to be renegotiated. This means that a firm's decision in the current period will be affected by its beliefs about the regulator's commitment to a certain policy and implies that a ratchet effect could be present.

Furthermore, there are two types of agreement: individual and branch agreements. This paper analyzed individual agreements. Industry branch agreements have been implemented where this saves on administration costs. Depending on the diversity in energy use, the suitability of individual agreements differs between industrial branches. The choice between individually based regulation and branch agreements saving on administrative costs is important to explore given that it opens up for free riding and accountability problems.

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Appendix: Assumptions on the Pollution and Production Functions

Differentiating the first order condition for optimal energy use, equation (5):

$$\frac{\partial \pi(e^{*}(\theta),\theta)}{\partial e} = t\frac{\partial z(e^{*}(\theta),\theta)}{\partial e}$$

gives $$\frac{d\,e^{*}(\theta)}{d\theta} = \frac{t\dfrac{\partial^{2} z(e^{*}(\theta),\theta)}{\partial e \partial \theta} - \dfrac{\partial^{2}\pi(e^{*}(\theta),\theta)}{\partial e \partial \theta}}{\dfrac{\partial^{2}\pi(e^{*}(\theta),\theta)}{\partial e^{2}} - t\dfrac{\partial^{2} z(e^{*}(\theta),\theta)}{\partial e^{2}}}$$

Given our assumptions on a concave production function and a convex pollution function in e, the denominator is negative. The sign of $\frac{d\,e^{*}(\theta)}{d\theta}$ is thus positive (negative) if $\frac{\partial^{2}\pi}{\partial e \partial \theta} > 0$ (<0) and $\frac{\partial^{2} z}{\partial e \partial \theta} \le 0$ (≥0). When $\frac{\partial^{2} z}{\partial e \partial \theta} = 0$, the sign of $\frac{d\,e^{*}(\theta)}{d\theta}$ is directly identical to the sign of $\frac{\partial^{2}\pi}{\partial e \partial \theta}$.[7]

The assumption on $\frac{\partial z}{\partial \theta} < 0$ together with the assumption on $\frac{\partial^{2}\pi}{\partial e \partial \theta} < 0$ implies the argument of Khanna and Zilberman (1997) that much pollution is generated from inefficient input use. Khanna and Zilberman (1997) document several production processes for which this assumption seems reasonable, for example, the

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[7] To simplify notation, arguments of functions in derivatives are omitted.

transformation of fossil fuels into electricity. If $\frac{\partial^2 \pi}{\partial e \partial \theta} < 0$, a high value of θ unambiguously implies lower pollution. If $\frac{\partial^2 \pi}{\partial e \partial \theta} > 0$, the direct effect from higher values of θ implies lower pollution but at the same time an increase in pollution resulting from increased use of input. An example is the so-called "rebound" effect from increased energy efficiency. The more fuel-efficient equipment, the less pollution resulting from input waste, but input use might also increase with the increased marginal productivity and outweigh the direct effect. This illustration makes the explanation of the sign of $\frac{d z^*(e^*(\theta),\theta)}{d\theta}$ more intuitive. Since $\frac{d z^*(e^*(\theta),\theta)}{d\theta} = \frac{\partial \mathrm{z}}{\partial \theta} + \frac{\partial \mathrm{z}}{\partial \mathrm{e}} \frac{\mathrm{de}^*}{\mathrm{d}\theta}$, $\frac{d z^*(e^*(\theta),\theta)}{d\theta}$ is negative when $\frac{d e^*(\theta)}{d\theta}$ is negative, or, when $\frac{d e^*(\theta)}{d\theta}$ is positive but not so large as to outweigh the direct effect from $\frac{\partial z}{\partial \theta}$.

A necessary condition for $\frac{d z^*(e^*(\theta),\theta)}{d\theta}$ to be positive is therefore $\frac{\partial^2 g}{\partial e \partial \theta} > 0$ and $\frac{\partial z}{\partial \theta}$ relatively small.