Discussion Paper No. 11-040

The Impact of Informational Costs in Quantity Regulation of Pollutants

The Case of the European Emissions Trading Scheme

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Non-Technical Summary

The Kyoto Protocol mandates a reduction of greenhouse gas emissions to countervail climate change. As a consequence, the EU has introduced the European Emissions Trading Scheme (EU ETS) to achieve a reduction of CO_2 emissions of 21% on average among energy producers and energy intensive industries until 2020. The regulated firms are heterogeneous in terms of annual emissions levels and employed technology. Since there are currently no end-of-pipe technologies available for CO_2 abatement, firms have to optimize processes or invent new technologies in many cases to achieve emission reductions. If emissions occur as a byproduct of complex processes as it is often the case in the EU ETS, firms will face informational costs when searching for abatement options or when evaluating costs for abatement. This is in contrast to other regulatory schemes, like the US SO_2 trading scheme. Within the US SO_2 trading scheme one specific technology was regulated, namely the combustion of fossil fuels for energy production. Moreover, when the SO_2 trading scheme was introduced there were mature end-of-pipe technologies available on markets (i.e. scrubbers), offering abatement options at low informational costs.

In this paper we present a model that highlights the importance of technological complexity and firm-size in environmental regulation. If regulated firms emit a relatively small amount of pollutants, possible efficiency gains from abatement are also relatively small. If there are high informational costs for abatement options and costs to be identified because of complex technology, small emitters might face a threshold for searching for abatement technology. This could effectively hamper the implementation of existing abatement technologies and the invention of new ones.

The model presented in this paper has several implications for the optimal design of environmental regulation, i.e. if regulated technological processes are complex, as in the case of greenhouse gas abatement. Induced technological change can be hampered if regulated sources emit only small amounts of pollutants. The problem can be resolved if informational costs for abatement options and the discovery of abatement costs are reduced, e.g. by strengthening collaboration in research and development, fostering and incentivizing technological transfer, strengthening markets for abatement technologies or promoting basic research. Reducing uncertainty with regard to future regulation can also reduce informational costs, e.g. by announcing price-floors in quantity based regulation. Alternatively, smaller emitters could be opted-out of regulation. Further research has to be conducted with regard to the optimal mix of additional measures to environmental regulation in situations where a complex technology is employed and to the optimal coverage of firms and technology.

Das Wichtigste in Kürze

Zum Schutz des Weltklimas haben sich zahlreiche Staaten im Rahmen des Kyoto Protokolls dazu verpflichtet, ihren Ausstoß an Treibhausgasen zu senken. Dazu wurde in Europa ein Handelssystem für Treibausgasemissionen eingeführt. Durch das Europäische Emissionshandelssystem (EU EHS) soll der CO_2-Ausstoß bei Energieversorgungsbetrieben und in der Industrie bis 2020 um 21% reduziert werden. Die im EU EHS regulierten Unternehmen sind in mehrfacher Hinsicht heterogen. Zum einen unterscheiden sie sich deutlich in ihren jährlichen Emissionsmengen, zum anderen ist auch die verwendete Produktionstechnologie, bei deren Nutzung CO_2-Emissionen anfallen, höchst heterogen. Da es bisher keine einfache Möglichkeit gibt, CO_2-Emissionen zu mindern, z.B. durch nachsorgende additive Vermeidungsmaßnahmen (engl. end-of-pipe), müssen Vermeidungsoptionen in vielen Bereichen individuell für einzelne Prozesse entwickelt werden. Den regulierten Unternehmen können bei der Suche nach passenden Technologien zur CO_2-Minderung Such- und Informationskosten entstehen. Damit unterscheidet sich das EU EHS von anderen Schadstoffregulierungssystemen, etwa dem US-amerikanischen SO_2-Handelssystem. Im US SO_2-Handelssystem wurde im Wesentlichen nur eine Technologie reguliert, nämlich die Verbrennung von fossilen Rohstoffen zur Energiegewinnung. Zudem waren nachsorgende additive Vermeidungsmaßnahmen (insb. SO_2-Waschanlagen) auf Märkten verfügbar.

In diesem Aufsatz wird ein ökonomisches Modell präsentiert, das anhand eines Vergleiches der oben genannten Systeme aufzeigt, welche Bedeutung technologische Komplexität von Schadstoffvermeidungstechnologien und Heterogenität von regulierten Unternehmen für die Ausgestaltung von Schadstoffregulierungssystemen haben kann. Ein hoher Grad an technologischer Heterogenität kann dazu führen, dass Vermeidungstechnologien nicht in ausreichendem Maße durch Märkte zur Verfügung gestellt werden, insbesondere dann, wenn bestimmte Technologien nur von einer geringen Anzahl von regulierten Emittenten genutzt werden. Sind die technologischen Prozesse komplex, so kann dies zudem zu relativ hohen Such- und Informationskosten für die regulierten Emittenten führen. Da regulierte Unternehmen mit relativ geringen Emissionsmengen im Durchschnitt auch geringere absolute Potenziale zur Kostensenkung aufweisen als größere Emittenten, kann es zu Situationen kommen, in denen Such- und Informationskosten kleinere Emittenten oder Unternehmen mit hoher technologischer Komplexität an der Identifikation oder Entwicklung von Vermeidungstechnologien hindern.

Aus dem Modell leiten sich wichtige Erkenntnisse für eine optimale Regulierung von Schadstoffen ab, die unter komplexen technologischen Prozessen anfallen. Dies hat besondere Relevanz in Hinblick auf die Regulierung von Treibhausgasen. So zeigt sich, dass induzierter technologischer Wandel gehemmt werden kann, wenn vornehmlich kleine Emissionsquellen reguliert werden, die komplexe technologische Prozesse verwenden. Dem kann durch eine Minderung der anfallenden Such- und Informationskosten entgegengewirkt werden, etwa durch die Stärkung von Forschungskooperationen und Wissensaustausch, die Stärkung und Vernetzung von Märkten, die benötigte Technologien entwickeln und anbieten können, die Verringerung der Unsicherheit über zukünftige Kosten der Regulierung in einem mengenbasierten Regulierungssystem wie dem EU EHS oder dem Ausbau der Grundlagenforschung. Alternativ wäre es möglich, kleinere Emittenten aus der Regulierung auszunehmen oder anders zu regulieren. Weiterer Forschungsbedarf besteht noch hinsichtlich der Maßnahmen die sich optimal zur Flankierung bestehender Regulierungssysteme eignen (policy-mix) bzw. der Bestimmung des optimalen Umfangs von Regulierungssystemen.

The Impact of Informational Costs in Quantity Regulation of Pollutants

The Case of the European Emissions Trading Scheme

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Abstract

There is extreme heterogeneity of firms regulated under the European Emissions Trading Scheme (EU ETS) in terms of emissions levels and employed technology. We present a model that shows that behavior of firms under quantity regulation can differ strongly, dependent on the characteristics of the firms when the assumption of full information is relaxed. If there are informational costs with regard to abatement options and costs, relatively small emitters and emitters with relatively complex technology will face a threshold for evaluating abatement options and costs. We compare the EU ETS to the US SO_2 trading scheme and show that "adjoining" markets to quantity regulation, supplying goods (i.e. abatement technology) or services (i.e. assistance in permit trading), play a crucial role to reduce transactions costs. Given high complexity of technology and/or strongly limited demand for certain technologies, markets will fail to provide appropriate assistance, generating efficiency losses. The presence of technological complexity and heterogeneous firms can have major consequences for the design of environmental regulation, when considering transaction costs.

JEL-Classification: Q52, L22, O31

Keywords: Quantity Regulation, Transaction Costs, Technological Complexity, Induced Technological Change, Emissions Trading

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1 Introduction

Firms do not have full information. Surveys among German firms in the European Emissions Trading Scheme (EU ETS), which aims to reduce greenhouse gas emissions in the European industry and energy sector by 21 percent until 2020, confirm this proposition. For example, it shows that 65 percent of German firms regulated by the EU ETS did not evaluate costs and options for greenhouse gas abatement between 2005, when the scheme started, and 2010. Most importantly, small emitters are less active in the EU ETS in general. Among emitters that have already evaluated costs and options for abatement, the median of emissions was 90,000 tCO_2 in 2009 and hence three times higher than among emitters that did not evaluate costs and options for abatement. Small emitters are less active not only with regard to information on abatement options. Among emitters with less than 25,000 tCO_2 emissions in 2009, only 50 percent actually implemented abatement in 2005 to 2010, compared to 62 percent among larger emitters ($\geq$ 25,000 tCO_2). 60 percent of small emitters did not trade permits, compared to 40 percent among larger emitters. 55 percent of small emitters stated that cost minimization with regard to the EU ETS is of secondary importance for their company, compared to 33 percent among larger emitters. It shows that 98 percent of emissions, covered in the EU ETS in Germany, stem from firms that actually aim to minimize costs, however, the remaining two percent of emissions stem from firms that do not primarily aim to minimize costs and seek to comply with the EU ETS in the first place (Detken et al, 2009; Löschel et al, 2010).

Why is that? We expect large emitters to be able to generate larger gains in the EU ETS by optimizing processes. On the other hand, transaction costs could hamper cost minimization among smaller emitters, implying that the expenditures from gathering information are larger than the expected gains from doing so. Managing carbon, hence, could depend on the initial emissions level of regulated firms. Or alternatively, the efficient degree of effort invested in optimizing processes under regulation could differ among firms of different emissions level.

In addition to that, there is a technological dimension. Highly complex processes might require more effort for optimization (Matisoff, 2010). This is especially important if there are no marketable abatement options, like in the case of greenhouse gases, where currently no end-of-pipe technology exists. This is in strong contrast to other quantity based regulatory schemes, like the US SO_2 trading scheme. In the SO_2 trading scheme there were easily available abatement options. While abatement options themselves, like scrubbers, were by no means cheap, informational costs for searching appropriate abatement options can be considered sufficiently small. Hence, markets that supply abatement technology or services related to trading of permits, might highly contribute to make quantity regulation easier to manage for regulated firms. While informational costs (or transaction costs in general) can also occur under regulation by tax, we focus on quantity regulation because it has become increasingly prominent for the regulation of greenhouse gases in recent years. For example, the Kyoto protocol mandates a reduction by quantities, the EU ETS is a quantity based scheme, New Zeeland currently installed a quantity based greenhouse gas regulation scheme and countries like the USA, Japan or Australia have discussed quantity approaches to regulate greenhouse gases. Moreover, it allows for comparing transaction costs for trading of permits and the identification of abatement options. Hence it helps to illustrate the impact of technological complexity, which can be regarded as variety of demanded products for abatement by regulated firms.

In this paper, we focus on informational costs for abatement, dependent on the initial emissions level of a firm and the complexity of employed technology. We briefly discuss the general idea of quantity regulation in the next section. In section three, we compare the EU ETS and the US SO_2 trading scheme and discuss the impact of informational costs in the EU ETS. In section four, we present a model that tries to take these informational costs in the behavior of firms under quantity regulation into account. In section five, the importance of markets for environmental regulation, or more precisely the impact of vertical vs. horizontal integration, is discussed. We finally discuss the results and try to derive solutions for the problem of transaction costs related to the identification of appropriate abatement options.

2 Standard Theory

The standard approach to quantity based regulation states that firms face a certain price p for tradable permits on the market and equate their marginal costs of abatement according to that price. When abatement costs are $c_i(e)$, firm i faces the problem

$$\min_{e} \; C_i = c_i(e) + p \cdot e_i. \tag{1}$$

The firm aims to minimize total costs C_i from the quantity based regulation which stem from the costs of abatement $c_i(e)$ and the costs for purchasing permits at price p for each unit of emissions e_i. Deriving the total costs for e yields the optimal (cost minimizing) emissions level e^*

$$\frac{\delta C_i}{\delta e} = \frac{\delta c_i(e)}{\delta e} + p.$$

The optimal emissions level e^* is located where marginal abatement costs are equal to the marginal price for emitting one unit emissions p and the firm adjust their emissions from the initial level e_i^0 to the optimal level e^* in order to minimize costs

$$\left.\frac{\delta C_i(e)}{\delta e}\right|_{e_i^*} = p^*.$$

The idea of tradable permits goes back to the contributions of Coase (1960), Crocker (1966) and Dales (1968) who forulated the idea in a qualitative way and Baumol and Oates (1971)[1] and Montgomery (1972) who showed that a scheme of tradable permits can yield an efficient allocation of emissions. The most important fact here is that each firm perceives the same price (marginal costs per purchased permit). Thus, if each firm individually adjusts its emissions according to the cost minimizing marginal condition above, marginal abatement costs are equalized between all sources within the economy. As a consequence there is no regulated source (firm or installation) that would be able to abate more efficiently than any other. Following Weitzman (1974),

[1] Tietenberg points out that Baumol and Oates (1971) demonstrated formally that the qualitative model by Crocker (1966) and Dales (1968) was correctly anticipated. As Tietenberg (2006, pp. 4-5) says: *"The final stage [...] was reached with the publications of a couple of now classic articles. The first, by Baumol and Oates (1971), formalized the theory behind these practical insights for the case of uniformly mixed pollutants, those for which only the level, not the location, of the emissions matters. This was followed shortly by an article by Montgomery (1972) that generalized the results for the more complicated case of non-uniformly mixed pollutants [...]".*

tradable permits can have a comparative advantage compared to regulation by prices (tax) if and only if the slope of marginal benefits from regulation is steeper than the slope of marginal costs. With regard to environmental effectiveness it has to be said that, given a *fixed* emissions constraint or offset baseline, a scheme of tradable permits is expected to deliver the *targeted* amount of emissions (or emissions reduction) at least costs. This is in contrast to a tax scheme. Using taxes, emissions reductions can also be achieved at least costs, but since a tax sets a fixed price, the actual emissions reduction is in practice uncertain due to a priori unknown marginal abatement costs (see Hahn and Stavins, 1992 and Stavins, 2008).

In standard theory, there are no costs for using markets, like the market for emissions permits or the market for abatement technology, and firms have full information (i.e. about permit prices and the shape of the marginal abatement costs curve). There are few papers that address transaction costs for the case of tradable permits. Stavins (1995) and Montero (1997) focus on issues related to permit trading. Hanemann (2009) points out that in cases where assumptions from standard theory are relaxed, the way of allocation of permits (free allocation vs. auctioning) can have an impact on the final allocation of emissions[2].

Today there is a large and still growing body of literature related to organizational issued in economics in general that augments classical theory. Starting with Coase (1937), puzzling about the nature of the firms, over Leibensteins X-inefficiency (Leibenstein, 1966), to Alchian and Demsetz (1972), and Williamson (1979), to name a few. A common feature to all these contributions is the question of what motivates the use of markets versus the use of hierarchies and what exactly the nature of the process of production under coordination inside a firm is. Costs for transacting or alternatively, costs for using markets instead of hierarchies, play an important role here. In the next section we briefly discuss the importance of markets in general and the importance of costs for using markets in particular for the case of tradable permits. By doing so we focus on the case of informational costs related to abatement.

[2] This can be inter alia due to risk aversion of firms and because of an *endowment effect* on the firm level.

3 The Role of Informational Costs

Informational costs can play an important role in determining the optimal output under quantity regulation. In practice, firms need to gather information and to accumulate knowledge with regard to the market for tradable permits, abatement technologies, and other management issues related to emissions trading. In addition, there are adjoining markets being used due to the regulatory scheme, i.e. markets for abatement technology and financial assets like futures and options for emission permits. Informational costs or transaction costs under regulation also depend on the state of adjoining markets, i.e. if they are mature markets that can be easily used without high costs of transacting. This also points out the evolutional character of any regulatory scheme. Not only regulated firms have to adapt to a newly installed regulatory scheme. Adjoining markets will also evolve over time or existing markets will adapt to the new scheme (i.e. when demand for certain goods or services, like trading of permits or abatement technology is generated through environmental regulation). Considering transaction costs under regulation, the possibility of using markets instead of hierarchies should be regarded as a driving force for overall efficiency. The basic questions are, first, which commodities or capabilities[3] under quantity regulation demanded by regulated firms can be traded on adjoining markets, and second, when and why regulated firms will use markets or hierarchies to minimize costs under quantity regulation.

Informational costs related to trading of allowances include the costs for conducting certain transactions as well as evaluating the need for transactions and their timing. Evaluating the need for transactions is necessary because firms usually have the obligation to surrender emission permits for each compliance period at a certain point in time. Hence, it must be ensured that an adequate number of permits is available for compliance. Since permit prices vary over time, firms have to take future costs of environmental regulation

[3]Such commodities or capabilities could be abatement technologies, alternative fuels for fuel-switching or services like technical assistance or permit trading and management by intermediaries.

into account when investment decisions are made[4]. Taking the European Emissions Trading Scheme (EU ETS) as an example, installations within the EU ETS have a lifecycle of 30 to 40 years in average (Löschel et al, 2010). When investment decisions for durable goods under regulation are made, firms would have to take the potential regulatory costs over the whole life cycle into account. Since there is currently high uncertainty about the future stringency of greenhouse gas regulation under the EU ETS, informational costs with regard to a long term assessment of prices will occur and the inclusion of a risk premium for investment under uncertainty is likely[5]. When the simple examples mentioned above hold, quantity regulation under uncertainty, like in the case of the EU ETS, clearly is second best, compared to the theoretical case of full information. While this is by no means a novelty, it nevertheless highlights the potential impact of informational costs and the impact of uncertainty on markets that are related to regulation by quantities.

Informational costs for identifying abatement options and evaluating the related costs might in some cases be far more important than costs related to permit trading. Comparing the SO_2 trading scheme under the Clean Air Act in the USA to the European Emissions Trading Scheme can serve as an illustration here. While there were available standardized abatement technologies under the US trading scheme for SO_2, which started in 1990, there are rarely standardized abatement options for greenhouse gas emissions available on markets in the EU ETS. In particular, the non-availability of end-of-pipe technologies for CO_2 abatement and the limited options for replacing fossil fuels are of great importance in the case of greenhouse gas abatement. The most important options for SO_2 abatement in the USA were coal switching (to low-sulfur coal) and the installation of scrubbers (Hanemann, 2009).

[4]In practice this implies the evaluation of future permit prices as well as an evaluation of the future stringency of regulation. Within the EU ETS prices are expected to rise over time because of the decreasing overall cap on greenhouse gases in Europe. Uncertainty regarding the future climate policy in Europe, such as the possibility that the EU could raise their emissions reduction target from currently 20 percent to 30 percent (greenhouse gas reduction until 2020 compared to 1990), represents general uncertainty about regulation. Both aspects, price development under existing regulation and possible changes in future regulation, must be considered for an evaluation of future costs to be consistently derived.

[5]Uncertainty played an important role in the US SO_2 trading scheme. As Hahn and Hester (1989) pointed out: *"Thus, the lack of clearly quantifies property rights created a disincentive for firms to create surplus emissions reductions and to participate in emissions trading"*. Although the US SO_2 trading scheme and the EU-ETS differ in many aspects, existing uncertainty might hamper an efficient implementation of emissions reductions and trading activities in both schemes.

Starting in 1990 prices for scrubbers dropped while their efficiency increased (Taylor, Rubin and Hounshell, 2003; Popp, 2003). Ellerman and Monterro (1998) and Ellerman (2003) reported that there was also an increased use of retrofitted scrubbers combined with the use of higher-sulfur coal as a cost minimizing strategy. As Burtraw (1996) and Hanemann (2009) point out, there was competition between the suppliers of abatement options (low-sulfur coal and scrubbers combined with the option of changing the dispatch order of plants) which actually led to a reduction in overall abatement costs over time.

An important feature of the SO_2 trading scheme, when comparing to the EU ETS, was the availability of marketable abatement options. As Hanemann (2009) points out, scrubbers were a mature technology when the SO_2 trading program entered into force. Moreover, the availability of low-sulfur coal represents an abatement option through adjoining markets (not a technological abatement option)[6]. The fact that there was some kind of competition between inputs helped to decrease abatement costs over time. This is a feature of markets that are not directly related to SO_2 trading, but induced through the trading scheme. New markets evolved, like the market for scrubbers, or existing markets were changed, like the market for coal, because of demand generated through environmental regulation. This highlights the importance of well-functioning adjoining markets for abatement options beyond the trading scheme per se.

In particular, the SO_2 trading scheme addressed *one* specific industrial process, namely coal combustion for power generation. As a consequence standardized abatement options evolved and were broadly applicable. This is in strong contrast to the situation in the EU ETS, which covers a wide range of different activities, products, technologies and industrial processes in general. The list of product benchmarks[7], developed by the European Commission as baseline for free allocation of permits after 2012, can serve as an illustration here (EU, 2010a). It contains a list of 116 different industrial processes considered for the definition of benchmarks for free allocation of permits. Consequently, it is necessary to think about quantity regulation

[6]As Ellerman (2003) and Hanemann (2009) point out, the US coal market changed inter alia due to the introduction of the SO_2 trading scheme. Hence, the coal market adapted to the new situation in terms of supplying more low sulfur coal.

[7]The product benchmarks do not cover all relevant technologies within the EU ETS. This is because it only considers the sectors exposed to the risk of carbon leakage (EU, 2010b) and second because the benchmarks are defined as product benchmarks and not primary as technology benchmarks.

not primary in the way of regulated pollutants, but also in the way of addressed technologies and products. This is what the European Commission actually does in terms of free allocation of permits in the EU ETS after 2012.

What are the consequences of large technological diversity in environmental regulation and in quantity regulation in particular? If the range of technical processes within a regulatory scheme is large, the complexity of the overall scheme and the complexity of the adjoining markets for abatement technology are also large. What is the impact of the technological complexity of abatement on the costs for searching for abatement options and discovering the related costs? Here the central assumption of full information, made by standard theory, is clearly not applicable. Firms usually do not know their abatement costs a priori when technology is complex and might face costs for gathering information. These informational costs could potentially hamper abatement and alter the overall efficiency of the regulatory scheme by partly removing the "one price fits all" property of the standard theory approach or when firms in general refuse to examine costs because of X-inefficiency (Leibenstein, 1966). X-inefficiency refers to a situation where firms fail to minimize all costs due to a lack of competitive pressure or because competitive pressure is not perceived by the relevant parts of a multi-person firm.[8].

The decision to search for abatement options and costs and the decision to implement abatement can be seen as two different processes. If abatement options and abatement costs are known, the firm will implement these options given that it is a cost minimizing strategy. If abatement options and abatement costs are unknown, the firm will decide to search for information if the expectation is that the gathered information will actually contribute to cost minimization.

Given the large technological diversity in the EU ETS the next question is whether heterogeneity in the emission intensity of regulated firms could be an issue. Since the nature of abatement in general is incremental, meaning that abatement options are implemented so that a shift in the emissions intensity occurs, it is reasonable to expect small emitters to realize smaller incremental absolute emissions reductions than larger emitters which employ the same technology. Hence, smaller emitters might realize smaller absolute efficiency

[8]Also with regard to X-efficiency, the size of a firm, its overall emissions-level and the perceived costs of regulation might be of importance. A small firm that can potentially generate small efficiency gains through abatement only might not choose to evaluate costs because of a lack of institutional or monetary pressure, i.e. when permits are allocated for free.

gains or absolute cost savings compared to larger emitters when implementing abatement options to approach a cost-minimizing state of emissions, implying that initial emissions e_i^0 are higher than cost minimizing emission e_i^*. One may assume that investment costs for implementing abatement options are positively correlated with the amount of overall emissions of an installation. On the other hand, it is not necessarily true that informational costs are correlated with the overall amount of emissions. Informational costs could occur as some kind of fixed costs dependent on the technological complexity of processes or the availability of abatement solutions on markets. This could impose a threshold for searching on smaller emitters, given relatively small potential efficiency gains, and, hence, hamper abatement.

Discussing the importance of informational costs, or costs for managing abatement in general, three aspects have to be considered:

1. The magnitude of efficiency gains:
   From standard theory it is clear that the magnitude of efficient abatement defines the magnitude of efficiency gains. When a regulatory scheme is phased in and the initial emissions of a firm are greater then optimal emissions ($e_i^0 > e_i^*$), given permit price p^* and technology specific marginal abatement costs, gains from abatement, based on equation (1), are

$$G_i = p \cdot (e_i^0 - e_i^*) - \int_{e_i^*}^{e_i^0} c_i'(e)de. \tag{2}$$

   Deriving gains G_i for initial emissions e_i^0 yields

$$\frac{\delta G_i}{\delta e_i^0} = p - c'(e_i^0).$$

   When $e_i^0 > e_i^*$, a higher initial emissions level e_i^0 yields higher gains, given a certain marginal abatement cost curve $c_i(e)$, defined by employed production technology. Hence, small emitters might realize absolute smaller gains via efficient abatement compared to large emitters employing the same technology. This would be true if emissions reductions of X percent in average would be optimal for a given technology and initial firm specific emissions level e_i^0.

Although this is an assumption that needs to be proven empirically, it appears not to be not too restrictive. However, when modeling efficiency gains from approaching an optimal emissions level trough abatement, it should be assured, that gains are represented in such a general way that economics of scale, linear gains or diseconomics of scale can be captured by the model.

2. Complexity of processes and technological heterogeneity:
   The second aspect is not covered by standard theory and has been rarely discussed in the literature to our knowledge: the complexity of processes can influence the identification of abatement options that are efficient from the standard theory point of view. The idea behind this is that the more complex the production process in which emissions occur, the more complex the implementation of abatement options. First, because appropriate and efficient measures have to be identified and second, because changing complex processes might be relatively costly compared to changing less complex processes.

   The first argument is related to the general idea of transaction costs, i.e. costs for searching or informational costs, which do not occur in standard theory. The second argument is related to the nature of marginal abatement costs. The proposition above would imply that marginal abatement costs are higher for processes where emissions occur in a complex process compared to simpler processes. A similar statement was made before by Matisoff (2010).

   Here, the role of adjoining markets with th EU ETS is important. If there is a highly complex process, which, for example, occurs only a few times among the more than 10,000 installations within the EU ETS, there might be no market that supplies abatement options to the polluter. The polluter might in some cases rely on herself to generate abatement options or face extremely high informational costs. In certain cases, when there is no market for abatement technology, the firm might have to use hierarchies rather than markets to identify and generate abatement options, meaning innovating on its own[9]. This could have a large impact on the degree of efficiency in supplying

[9]One example for this is the case of the development of top gas recycling in steel production. The German government granted EUR 30.18 million of subsidies to Arcelor Mittal Steel in Eisenhüttenstadt in 2010 for the development of a technique for separation of CO_2 from top gas (EU, 2010c). Such a special abatement technology will be hardly supplied by adjoining markets and consequently has to be developed by the regulated firm.

abatement options because of issues related to the division of labor, specialization, the diversification of risks, in terms of enjoying scale economics, or Marshall-externalities. The technological scope of emissions trading combined with considerations of adjoining markets was rarely addressed up to now, but seems to be of great importance when comparing the EU ETS to other quantity regulation schemes, like the US SO_2 trading program. While permits might be "marketable" because they are a standardized good, many technologies, especially some of the technologies addressed in greenhouse gas abatement, might not be perfectly "marketable" because of their complex nature or market structures characterized by dual oligopoly.

3. Heterogeneity in overall emission levels:
   Firms within the EU ETS are highly heterogeneous in terms of annual emission levels. In Germany, about 50 percent of companies emited less than 25,000 tons CO_2 in 2010. These 50 percent of companies account for roughly one percent of annual emissions covered by the ETS in Germany. On the other hand, a few large companies account for about half of annual emissions in Germany[10]. Within the whole EU ETS, there were 10,221 active installations in 2010 according to the CITL[11]. 6,375 installations emitted less than 25,000 tCO_2 in 2010, while 3,846 had emissions of more than or equal to 25,000 tCO_2 in 2010. The inequality in emissions level can be shown by plotting the Lorenz curve over verified emission in 2010, leaving out those 642 installations that had zero emissions in 2010 (see firgure 1). It shows, that the installations are very uneven in their emissions levels, where the corresponding Gini coefficient is 0.878[12]. Is this very uneven distribution harmful?

   There are concerns about market power in the literature (Hahn, 1984; Montero, 2009). However, focusing on transaction costs or informational costs for abatement, there might be another problematic effect

[10]The four large German energy suppliers EnBW, E.ON, RWE and Vattenfall emitted 49 percent of verified CO_2 emissions covered under the European Emissions Trading Scheme in 2010 in Germany. These four companies emitted 222 $MtCO_2$ in 2010, where overall emissions, covered by the trading scheme in Germany, were 454 $MtCO_2$ in 2010.

[11]The Community Independent Transaction Log (CITL) lists the verified emissions of all installations covered by the EU ETS.

[12]The Lorenz curve and Gini coefficient are calculated on the installations level and not on the firm level. Aggregating all installations to the firm level is hardly possible for the whole EU since the data does not uniquely identify firms. Since there are some large firms, running many installations, the inequality is likely to rise when installations would be aggregated on the firm level.

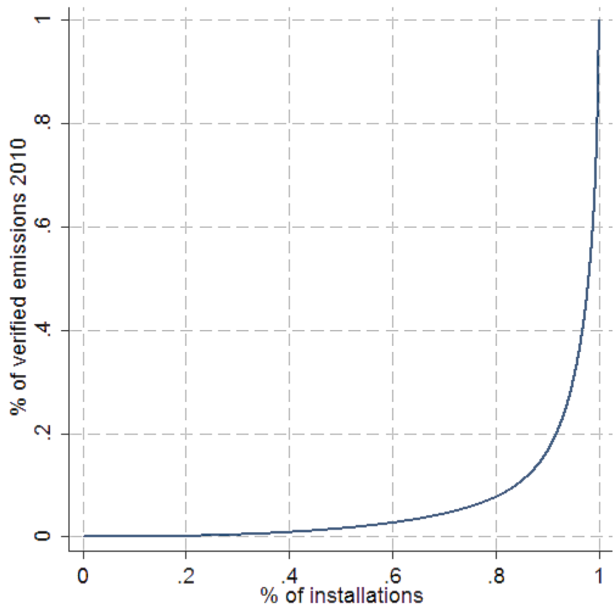

Figure 1: Lorenz curve of installations covered in the EU ETS and their verified emission in 2010

of heterogeneity, namely that small firms might face a considerable threshold when investing in abatement. As discussed above, firms with more complex processes might face high informational costs in general and some might not even have the option to use markets to find appropriate abatement options. In such a situation there is no more *make-or-buy* decision because of the non-existence of mature markets. Small emitters that cannot realize large efficiency gains might back away from investing in searching for abatement options, at least if the expectation is that the efforts will not pay-off in the end. If the proposition holds that possible gains from abatement increase with the overall initial emissions level of a firm and that firms face transaction costs and informational costs when searching for abatement options, then one would expect that the ability to abate in an efficient way differs between larger and smaller emitters. This means that some firms might not invest in searching for information on abatement, and, hence, do not abate, because of large informational costs. This could represent a cost minimizing strategy when informational costs are considered. However, the final allocation of emissions and abatement between regulated firms could be different in this case than expected by standard theory.

Wrapping up the discussion, it has to be said that under environmental regulation, where we consider a scheme of tradable permits here, not only the regulated pollutant defines the regulatory scheme. Moreover, the addressed technologies can play a crucial role for the full costs of abatement, assuming the existence of transaction costs (i.e. informational costs) and relaxing the assumption of full information and perfect markets. If this is true and if possible efficiency gains (cost savings) from abatement depend on the overall emissions level of firms, then firms of relatively small initial emissions level could face a threshold for abatement. In the next section, we specify the idea in a more formal and more detailed way.

4 The Model

4.1 A Simple Approach

An easy approach to the problem of informational costs for abatement in the EU ETS would be to assume a certain value of fixed costs for information and to compare it to the expected value of efficiency gains that would stem from implementing an abatement option. The gain from implementing an abatement option is G_i for firm i when the initial emissions level is e^0 and the optimal emissions level is e^*, where it is assumed that $e_i^0 > e_i^*$. The firm employs *one* certain technology and the permit price is p^*. Then G_i is

$$G_i = p^* \cdot (e_i^0 - e_i^*) - \int_{e_i^*}^{e_i^0} c_i'(e)de.$$

Since firm i is monitored under the trading scheme, e_i^0 is known, p^* can be observed on the market for emissions permits and is fixed because we consider a static model for simplicity. The firm is not aware of its marginal costs of abatement $c_i'(e)$ and therefore also the optimal (cost minimizing) amount of emissions e_i^* is a priori unknown. The firm might have at least rough expectations about the options and costs of abatement. Therefore, the a priori expected abatement costs $E(c_i(e))$ are the basis for a firm's decision to search for abatement options or not. Expected gains $E(G_i)$ are then

$$E(G_i) = p^* \cdot (e_i^0 - E(e_i^*)) - \int_{E(e_i^*)}^{e_i^0} E(c_i'(e))de.$$

If the costs for information occur once, are known by the firm (i.e. costs for employing one person to evaluate abatement options), are dependent on the employed technology of firm i and have a fixed value C_i^I, then the firm can evaluate whether it is beneficial to search for abatement options and costs. This can be easily done by comparing searching costs and expected gains. A cost minimizing firm will choose to search for abatement options and costs if and only if the expected gains are higher than, or equal to the expected informational costs $E(G_i) \geq C_i^I$. The same principle can be applied with regard to trading of allowances, where the gains from a more sophisticated evaluation of trading options and strategies are compared to the costs for setting up the evaluation. Trading and searching for abatement options can be subsumed as *carbon management*. The goal of such management schemes is to make use of markets if possible or alternatively provide goods and services within the firms. The costs for carbon management in general can be regarded as transaction costs.

The simple model above illustrates the possible impact of transaction costs in environmental regulation when the assumption of full information and perfect markets is relaxed. Here, we focus on abatement, because abatement is more complex in the EU ETS than trading of permits. Within the US trading schemes, abatement options were relatively easily available on markets but permit trading was relatively complex and sticky (Hahn and Hester 1989; Hanemann, 2009). Thus, it is clear that, when designing quantity regulation, it is important to minimize transaction costs so that liquid markets for permits *and* abatement options can evolve (Tietenberg, 2006).

4.2 A Model With Technology and Firm-Size

From the simple model above it becomes clear that the implementation of abatement options depends on the initial emissions level e_i^0 which defines the expected gain and the complexity of technology which defines the informational costs for searching and the abatement costs in general. However, the representation above is quite simple and unsatisfactory. The model can be easily expanded when we are willing to accept some alternative assumptions instead of assuming full information and perfect markets that imply zero transaction costs.

The gains G_i for firm i are dependent on the firms historical predetermined emissions level e_i^0. In the following, we denote e_i instead of e_i^0 for simplicity, while still referring to the initial emissions level. The gains from equation (2) can be rewritten in a general form as

$$G_i(e) = \gamma \cdot e_i^z. \tag{3}$$

Here, z is a variable that defines the shape of the gain-curve of firm i dependent on initial emissions e_i and the employed technology γ. Since gains are expected to rise in the initial emissions level, it implies $z > 0$. When $0 < z < 1$ possible gains increase in e but less than e (decreasing marginal gains), implying $G_i(e)' > 0$ and $G_i(e)'' < 0$. When $z = 1$ there is a constant increase of gains in e with $G_i(e)' > 0$. When $z > 1$ gains increase in emissions e and rise in e (increasing marginal gains) with $G_i(e)' > 0$ and $G_i(e)'' > 0$.

In equation (3) above, γ is a shift parameter, allowing for a higher or lower level of gains dependent on the individual marginal abatement costs of firm i. If $\gamma > 0$ there are efficient abatement options that could be implemented by firm i. If $\gamma = 0$, gains are zero and abatement will be not considered[13].

The informational costs C_i^I which are transaction costs for using markets or hierarchies to find appropriate abatement technology and identifying abatement costs are dependent on the employed technology α of firm i. The reason is simply because we expect more complex technologies to come along with higher informational costs. Informational costs are given as

$$C_i^I(e) = \alpha \cdot e_i^y. \tag{4}$$

Here y is a variable that defines the shape of the informational cost curve of firm i with the same properties as z in G_i. The variable α is a level shift of informational costs due to more (or less) complex technology. Here, the employed technology α defines the searching costs jointly with y. If $\alpha = 0$, there would be no informational costs and abatement options would be always implemented when $G_i > 0$. This basically is the case of standard theory like shown in equation (1) above. If there are informational costs, than $\alpha > 0$. The higher α, the more demanding is searching for abatement options and the discovering of abatement costs, which we refer to as complex technology.

Informational costs are dependent on the initial emissions level e_i^0 of firm i, just as in the case of gains. The reason is simply because changing processes in large facilities might in average require more information than changing processes in small facilities given a certain technology. One example would be a long chain of combined installations that produce greenhouse gas emissions jointly as a byproduct as for example the case in the chemical industry or at refineries. Although each single process could be changed relatively easily in principle, each single processes is embedded in a larger production chain. Altering one part of the chain might often have an impact on the whole production chain and hence requires more information. However, since informational costs might not rise starkly with the initial emissions level it is

[13]If $z = 0$, gains would be equal independent of initial emissions. This case is not considered here. Given the large heterogeneity of initial emissions levels in the European Emissions Trading Scheme, it does not seem to be an adequate assumption that all firms can realize equal gains, independent of initial emissions. This would actually imply that a very small emitter could gain as much by implementing abatement as extremely large emitters like EnBW, E.ON, RWE or Vattenfall emitting jointly nearly half of emissions covered by the EU ETS in Germany.

straightforward to expect y to be relatively small. In addition to that we explicitly allow for pure fix costs, implying $y = 0$. This is in contrast to gains where it is assumed that $0 < z$.

Now firm i decides whether to search for abatement options and identify abatement costs or not, just like in the simple model above. Basically, the firm will search for abatement options if $G_i(e) \geq C_i^I(e)$[14]. We treat gains and informational costs as deterministic for simplicity. However, if gains and informational costs are uncertain, issues about risk aversion could further have an impact on the implementation of abatement options[15]. Now can derive the critical level of initial emissions $\tilde{e}$ of firm i for searching abatement options efficiently. Alternatively we can derive the critical level of technological complexity $\tilde{\alpha}$ given the initial emissions level e_i^0 of firm i. Before we do so, we briefly rearrange $C_i^I(e)$ and $G_i(e)$ for convenience.

Firms are indifferent whether to search or not when $C_i^I(e) = G_i(e)$. Dividing the equation by γ yields

$$\frac{\alpha}{\gamma} \cdot e_i^y = e_i^z$$

$$a \cdot e_i^y = e_i^z. \tag{5}$$

Redefining $\alpha/\gamma = a$ decreases complexity in the next steps. Here, a is the technological complexity (α) per unit gain (γ). This implies that high gains can potentially compensate for high technological complexity. However, the feasibility of the implementation of abatement still depends on the initial emissions level and technological complexity of firm i.

Resolving (5) for e and a yields the critical initial emissions level $\tilde{e}$ where searching for abatement options pays for firm i and the critical technological level $\tilde{a}$ that must not be exceeded for searching to pay

[14] Although we consider a static model with one time period, informational costs $C_i^I(e)$ can also be regarded as annualized costs for information. This could be relevant in practice when firms have to re-evaluate abatement options and costs from time to time.

[15] Risk aversion can either have a positive or negative impact. When a firm is risk-avers against investing in searching it will hamper abatement. When a firm is risk-avers in the sense that it fears high permit prices it probably will abate even under limited information. Sandoff and Schaad (2009) find some evidence for differing strategies of firms in the EU ETS.

$$\tilde{e} = a^{-\frac{1}{y-z}} \tag{6}$$
$$\tilde{a} = e^{-y+z}. \tag{7}$$

The critical initial emissions level $\tilde{e}$ is dependent on a and the critical technological complexity $\tilde{a}$ is dependent on e. The results imply that given a certain technology and gain structure $\alpha/\gamma = a$ there is a threshold for searching for abatement options and discovering abatement costs. The critical levels are also defined by the distance between y and z. When the absolute value of $y - z$ gets smaller, $\tilde{e}$ rises and $\tilde{a}$ falls.

The first derivations of (6) and (7) are:

$$\frac{\delta \tilde{e}}{\delta a} = -\frac{a^{-\frac{1}{y-z}-1}}{y-z} \tag{8}$$

$$\frac{\delta \tilde{a}}{\delta e} = (-y+z) \cdot e^{-y+z-1}. \tag{9}$$

If $y < z$, the first derivations are positive implying that the critical emissions level $\tilde{e}$ rises in a and the critical technological level $\tilde{a}$ rises with the initial emissions level e_i^0 of firm i respectively. This implies that the more complex technological processes, the higher the threshold for searching for abatement options and costs. Alternatively it can be said that the more complex the employed technology, the higher the initial emissions must be (and hence potential gains) so that it is a cost minimizing strategy to search for abatement options and costs.

It is necessary here to restrict the parameters to $y < z$, implying that informational costs rise less in emissions than gains. This is by no means a restrictive assumption because if informational costs exceed gains in principle, then no firm would abate. In contrast, informational costs can be expected to be nearly fixed-costs, only slightly rising in emissions, implying a relatively small value of y. Standard theory expects informational costs to be zero or at least close to zero because of full information or nearly full information, also implying perfect markets for abatement technology that can be used at zero costs. Removing the assumption of full information and perfect markets does not necessarily imply extremely high informational costs. To adjust informational costs to different situation we introduced "technical complexity", however, for abatement options to be implemented at all in the presence of informational costs, these costs must be modest in most situations, implying $y < z$.

z	y	γ	α	a
Shape of gain-curve	Shape of cost-curve	Level of gain-curve	Level of cost-curve	Ratio of complexity
$0 < z$ where $z > y$	$0 \leq y \leq 1$	$0 < \gamma$	$0 \leq \alpha$	$=\alpha/\gamma$

Table 1: Overview of variables in the model

Figure 2 illustrates the model by showing the critical emissions level $\tilde{e}$ dependent on z and the technical complexity $a = \alpha/\gamma$, where it is assumed that $y = 0.2$. As the figure shows, the critical initial emissions level $\tilde{e}$ rises starkly when z approaches y and when a rises. When z is close to y it implies that the gain curve and the informational costs curve are very close to each other. Consequently, relatively low gains compared to informational costs induce a rising initial emissions level $\tilde{e}$. When $a = \alpha/\gamma$ rises, it implies that technological complexity is large compared to gains and, hence, the critical initial emissions level $\tilde{e}$ rises. The lines in the figure mark the points where $z = 1$ and $\alpha = 1$. Where $a < 1$, the technological complexity is uncritical and searching for abatement options and costs is nearly always feasible from a transaction costs point of view. Where $z < 1$, gains rise in emissions but marginal gains decrease, $z = 1$ represents linear gains and $z > 1$ would imply increasing marginal gains. Especially when $a > 1$ and $z < 1$, transaction costs play an important role for the feasibility of abatement. It is reasonable to expect marginal gains that decrease in initial emissions ($z < 1$) or be nearly linear ($z \approx 1$) rather than strongly increasing marginal gains. Hence, technological complexity might in fact pose a threshold to abatement to many small emitters when technological processes are complex.

The concept of technological complexity $a = \alpha/\gamma$ is twofold here. On the one hand, technological complexity of course is related to the costs for abatement technology. However, if there is a certain applicable abatement technology available, the costs that represent the pure technological complexity are captured by marginal abatement costs and, hence, might have an impact on γ rather than on α. High abatement costs would have an impact on possible gains and, hence, lower γ, while low costs might lead to a high γ. A low γ (high costs) leads to an increasing a et vice versa, because of $\delta a/\delta\gamma < 0$. On the other hand, α refers to the marketability of abatement technologies, as

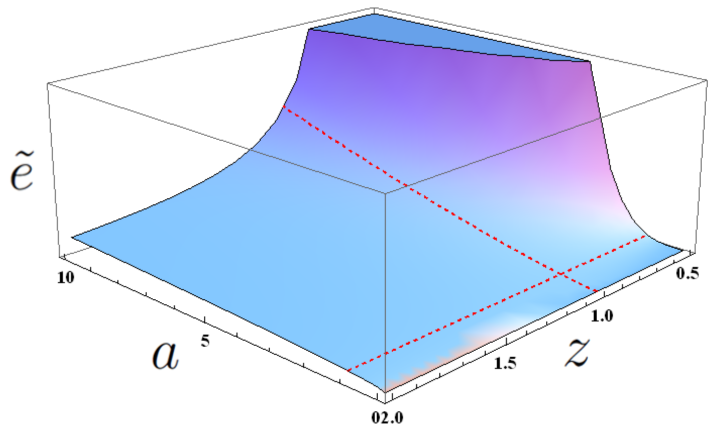

Figure 2: The critical emissions level $\tilde{e}$, dependent on z and a

illustrated for the case of the US SO_2 trading program. If technologies are not traded on markets and firms rely on themselves to invent or innovate, or if the market for technology is imperfect, then α might be large. We expect the markets for technology to be dependent on overall demand. Overall emissions within one technology E_i can serve as a proxi for demand, where $E_i = \sum_{i=1}^{n} e_i$. Marketability of technology rises in E_i, implying $\delta\alpha_i/\delta E_i < 0$ and hence, lowers the overall complexity a of the abatement technology because of $\delta a/\delta\alpha_i > 0$.

5 A Note on "Adjoining Markets"

It is unusual to use physical models in social science . However, the way how adjoining markets in an regulatory scheme evolve can probably be described in the sense of gravity. If there is a large possible demand for a certain good or service that stems from regulation, there will be intermediaries to provide those goods or services. The general expectation in economics is that incumbent intermediaries enter the market until marginal revenues from entering the market are zero. In the case of services related to permit trading, intermediaries have to provide *one* specific service, namely selling or purchasing of permits for their clients. Since all firms use the same permits, the service provided by financial intermediaries for trading is of relatively low complexity and it is likely that a mature adjoining market for permit trading will evolve due to high demand. This is why informational costs play a minor role in trading when there is a lively and transparent exchange of permits as it is expected to be the case in the European Emissions Trading Scheme.

While each firm uses the same kind of good in permit trading (i.e. one kind of permit), there is a large variety of employed production technologies in the European Emissions Trading Scheme. Some technological processes occur relatively often while others are highly specific and seldom employed. If one certain technology is used by a large number of firms, demand for abatement technology might be relatively large and intermediaries will enter the market. If there is a large number of intermediaries, specialization among intermediaries and competition between them will occur. Induced by the relatively large demand for abatement technology, various goods and services can be provided, generating a mature market for abatement technology. Thus, technical change is induced by the regulatory scheme. The existence of adjoining markets and the size of adjoining markets is crucial for specialization and competition in supplying alternative technologies (or abatement technologies) for production. Speaking in terms of gravity, a large demand for abatement technology for *one* certain production process a_1 will induce a large market to provide these abatement technologies, just like large mass will yield relatively high gravity. In contrast, if there is only a small potential demand for abatement technology for *another* certain production process a_2, the adjoining markets (or number of intermediaries) to provide these abatement technologies will be relatively small and less specialized, just like small mass yields relatively small gravity. The reason is simply because marginal revenues of intermediaries can be expected to approach zero much faster when overall demand is low. As a consequence, the optimal number of participants in adjoining markets (intermediaries supplying abatement technology) would be relatively small and specialization occurs to a smaller extent. This implies a less efficient provision of technological solutions on the supply side and higher informational costs on the demand side for abatement technology.

As an example, one could think about the development of a end-of-pipe technology in fossil fuel combustion, namely Carbon Capture and Sequestration (CCS). While CCS can be considered an extremely complex technology, there is also a potential high demand, given that the European Emissions Trading Scheme covers extremely large coal combustion installations. Large emitters, like RWE, BASF or Linde developed a joint research project on CCS. RWE for example tries to capture CO_2 from brown coal combustion and is currently testing CCS at a coal combustion plant in Hürth (Germany). This illustrates, that technological complexity is less important when potential gains are large. However, a complex technology like CCS and its related problems, like how and where to store CO_2, would most likely not be feasible if the value at stake were not millions of tons of CO_2 emissions, like in the case of RWE[16].

[16]RWE emitted some 104 $MtCO_2$ in 2010. This is about 23 percent of overall emission in Germany covered by the European Emissions Trading Scheme. Assuming a permit price of EUR 15, RWE's emissions in 2010 are "worth" more than EUR 1.5 billion.

6 Discussion

By comparing the US SO_2 trading scheme to the European Emissions Trading Scheme it becomes clear that the complexity of technology can play an important role in environmental regulation. Hence, regulatory schemes are not only determined by the regulated pollutant, but also by the technology that is applicable in abatement. When the assumption of full information and perfect markets for abatement technology are relaxed and transaction costs (i.e. informational costs) are considered, we can see that the initial emissions level of a regulated firm can influence the firm's ability to search for abatement options and the related costs.

While trading of allowances appeared to be relatively "complex" in the US SO_2 trading scheme because of imperfect property rights and high uncertainty, trading appears to be of relatively low complexity in the EU ETS. In contrast, abatement was relatively easily applicable in the US SO_2 trading scheme because all regulated firms used similar technology, namely the combustion of coal for energy production. Abatement technology like scrubbers or abatement options via markets like coal switching were easily available. However, in the EU ETS there is a large number of different, partly very specific processes. As a consequence, implementing abatement appears to be associated with relatively high costs for searching or transacting for some regulated firms. Moreover, some abatement technologies, like Carbon Capture and Sequestration (CCS) must be developed, pushing firms to invent abatement technologies themselves. Such inventions can hardly be carried out by very small emitters.

The model shows that, given a certain structure of potential gains and informational costs under regulation, small emitters will face a threshold for abatement if their employed technology is complex and abatement options are not traded on markets. This underlines the importance of "adjoining markets", especially for small emitters. Some abatement technologies can be provided in horizontal integration, e.g. in the case of the extremely large emitter RWE, which is developing an end-of-pipe technology to capture CO_2 for coal combustion. In contrast, processes used by several small emitters would require vertical integration of the market for abatement technology. If there is sufficient demand, implying a large number of small emitter, employing the same technology and demanding similar abatement options, markets will be able to provide these abatement options and informational costs will be modest. However, if there are only a few small emitters employing one certain process, informational costs could be large due to a small market for abatement technology or due to fractioned markets. These might provide technology that could be applied for abatement, but do not deliver a final abatement technology, requiring firms to assemble the final abatement technology themselves.

While the environmental effectiveness of the quantity based regulation is ensured if the emissions constraint ("cap") is ensured, the next question is how such a situation would influence economic efficiency. Informational costs that hamper abatement would then prevent the implementation of theoretically efficient abatement options among small emitters with highly complex processes. This would yield a situation where the "one price fits all" assumption of standard theory does not hold and effectively economic efficiency will be decreased compared to a situation without informational costs. However, the degree of inefficiency can be considered small given that small emitters have a small share on overall emissions within the regulatory scheme. In the German part of the European Emissions Trading Scheme for example, roughly one percent of emissions stem from approximately 50 percent of firms. While the number of potentially "inactive" firms is large, their potentials to contribute to inefficiency within the regulatory scheme is low.

Since potential inefficient emissions levels ($e_i^0 \neq e_i^*$) are persistent over time and additional costs, i.e. for additional permit purchases, occur each compliance period, it is surely reasonable to "invest" in an evaluation of abatement options. Why should firms not do so? One option is that firms could expect informational costs to decrease over time. This would imply that they expect markets for their required abatement technology to evolve or technological complexity to decrease in general, i.e. by a backstop technology to occur. Another option would be X-inefficiency, implying that a firm does not properly manage the trading scheme internally. Here, free allocation could play a crucial role. Small emitters with low potential gains will also have low potential gains in trading of allowances and hence will tend to neglect opportunity costs form freely allocated permits. This underlines the interplay of information inside a firm, capabilities, activities and transaction costs in trading, and abatement efforts. In general, it can be expected that firms will "discover" their abatement costs over time. The model presented here must be seen in that light. It does not necessarily imply that small emitters with complex processes will never gather information on abatement costs and options. What it does imply in its static framework, is that small emitters with complex processes will behave more sticky, adapt less quickly or frequently to new situations. This would also imply that frequent changes in the policy design or considerable volatility in the permit price could have negative impacts on small emitters.

What are potential solutions to these problems? One solution would be to choose strict upstream regulation if possible. This would implicitly pose a price also on small emitters, i.e. by charging fuel or other inputs. This will in most cases not change the problem of informational costs related to abatement, however, it releases small emitters from the duty of directly complying with the regulatory scheme. In addition, the management of a small emitter will not have to consider the permit price separately and manage permits. Prices are (in the best case) reflected in inputs and, hence, directly enter the production decision. In contrast, if a small emitter is regulated directly, it has to consider the permit price in addition to all other inputs. This might increase the overall complexity of regulation from the small emitter's point of view, i.e. when pollutants occur as a complex byproduct.

A tax would be a clear and reliable price signal for polluters. While a tax will not help to reduce informational costs with regard to abatement it nevertheless could reduce the complexity of regulation in some cases. Most importantly, the evaluation of possible future costs from regulation would be easier in many cases because under a tax there is no price volatility like in the case of tradeable permits. In general, there would be no need to manage permits, making the regulatory scheme easier to manage for small emitters. Since firms are used to the concept of taxes, but not necessarily to the concept of tradeable permits, the price per unit emissions might be perceived more directly, especially compared to free allocation of permits.

Another solution to the problem of transaction costs for small emitters would be an exclusion of small emitters, which had been proposed earlier for quantity based greenhouse gas regulation schemes in the USA or Australia and which will be possible for the European Emissions Trading Scheme from 2013 onwards[17]. While opting-out smaller emitter can be expected to have a relatively small impact on environmental effectiveness in the EU ETS, it could potentially increase economic efficiency. On the other hand, opting-out certain firms or installations would rise fairness issues, set perverse incentives for emitters and weaken the overall acceptance of the regulatory scheme. Based on the model the threshold emissions-level for opting-out firms differs between employed technologies. As an alternative to excluding firms or

[17] In the American Power Act and the proposal for the Australian Carbon Emissions Reduction Scheme, smaller emitters were excluded from regulation. In the EU, member states have the possibility to opt-out smaller installations of the European Emissions Trading Scheme if they are subject to adequate alternative regulation.

opting-out firms, small emitters could be opted-in to environmental regulation after a certain period of time. I.e. when larger emitters have developed abatement technologies and adjoining markets have involved.

Since the level of gains is dependent on the permit price, introducing a floor-price for permits, e.g. starting after a phase-in period, could strongly incentivize emitters to examine costs and options for abatement more accurately. Such a mixed approach of quantity and price based regulation would actually decrease uncertainty with regard to future prices within the regulatory scheme. In the presence of considerable informational costs, a mixed approach could help to increase efficiency by shifting possible gains from abatement upward (via the floor-price) and, hence, decreasing the role of informational costs compared to gains.

Alternatively, if informational costs were extremely large and by that were hampering the examination of abatement options in general or preventing private action, the generation and provision of abatement options could be regarded as a public good. This could be the case when radical inventions that require basic research are necessary. One example would be the case of a backstop technology that is able to replace fossil fuels with other fuels that do not release greenhouse gases to the atmosphere. With regard to greenhouse gas abatement this could be the case for many aspects, possibly implying revenue rising policies, if revenues are partly recycled to promote basic research on alternative technologies.

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