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Abstract

Trading schemes for emission allowances have become a panacea for nations aspiring to reduce their aggregate emissions of greenhouse gases from industry in a cost-effective manner. The contention of this paper is that an emissions trading scheme (ETS) should not be based on blanket coverage of installations on a downstream level, but should rather be designed to include some installations, and from some industrial sectors. In the case of an ETS there are high costs of administration, monitoring and transacting imposed on the installations covered. These costs are supposed to be more than offset by the cost savings realised through trading in the market for emission allowances. However, the paper shows that not all installations can fully offset administrative costs, and are therefore exposed to higher cost compared to a situation under an alternative instrument (e.g. standard). The paper formulates a conceptual framework for analysing overall cost and benefits from an ETS in the light of administration and transactions costs. It theoretically establishes a threshold point for optimal coverage of installations on a downstream level. The paper uses data from EU ETS to empirically determine optimal coverage for selected sectors. The results indicate that blanket coverage is more costly than the determined optimum coverage plan.

Key words: Climate Change, Emissions Trading Scheme, European Union, Marginal Abatement Costs, Environmental Policy

Introduction

Market-based instruments and emissions trading systems in particular, have gained prominence in recent time as a novel approach to reduce various types of pollution, including greenhouse gas (GHG) emissions. These instruments operate on the principle that property rights in GHG emissions can be defined and traded in markets. Market forces then provide incentives for beneficial trades among participants: emitters that can abate at low cost will invest and sell their excess permits, while emitters that

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have high cost of abatement buy emission permits. However, as a designer market, emissions trading systems may suffer from various shortcomings as a result of particular design choices being made when setting up the scheme. One design element, which is of particular interest of this paper, is the coverage of the scheme (Betz, 2003). When the market for tradable emission allowances is designed, the question arises as to which emitting entities are to be included in the system. Is it desirable to design a blanket system that includes every emitter of GHG, or should a more pragmatic approach be taken by looking at the cost and benefits of inclusion, and designing a system that will maximise the net benefits from such an inclusion? This paper will focus on the downstream coverage, which is the approach taken by the EU ETS. However, the proposals made for Australia are hybrid combining an upstream and downstream approach[1]. A preliminary conceptual framework in the direction of answering these questions, and some preliminary analysis based on data concerning *allowance allocation* from the European Union Emissions Trading Scheme (EU ETS) has been recently put forward (Betz and Ancev, 2006).

The current paper has two main objectives. One is to refine and improve a conceptual framework proposed earlier (Betz and Ancev, 2006) describing the problem of optimal inclusion (coverage) of emitting installations in an emission trading system. The other is to conduct an empirical analysis of the theoretical proposition for an efficient downstream coverage level in an emissions trading system. The empirical analysis is based on installation specific *emissions* data for 2005 from the EU ETS.

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[1] A *downstream* approach requires fossil fuel users to acquire permits compared to an *upstream* approach which requires permits to be acquired by fuel producers. The Australian proposals are described in National Emissions Trading Taskforce Report (2006) and Prime Ministerial Task Group on Emissions Trading (2007) report.

The key motivation for this research is the fact that GHG emitters in an economy form a widely heterogeneous body. On one hand, there are large emitters for which it is clearly beneficial to be included in an ETS. For these emitters the fixed costs of regulation in the system are relatively small compared to the benefits that they can enjoy as a result of being able to trade emissions allowances on the market (Betz, 2005; Schleich and Betz, 2004). On the other hand, there are a large number of smaller emitters that are likely to be mandated to participate in the ETS. For many of these emitters the costs of regulation are very high and there are almost no benefits from being able to participate in the system. A previous study (Betz and Ancev, 2006) found that 50% of the installations covered under the EU ETS, received less than 2% of the total allocated emission allowances. This suggests that the costs of operating such a blanket version of an emission trading system may be too high in comparison to benefits and that reducing the number of covered emitters, by for example raising the emission threshold for participation / coverage may in fact produce superior outcomes in terms of the cost for the system. While a previous study (Betz and Ancev, 2006) has proposed a theoretical model for determining an optimal level of coverage, it fell short of empirically testing the model in its entirety because of the lack of actual emissions data. Since such data have now become available, the present paper reports an expanded empirical analysis in the direction of looking for an efficient level of inclusion of installations in an ETS.

This paper focuses on the EU ETS due to data availability and the prominent treatment that this tradable permit system has received in the literature. European Commission (2000) reported that amongst other policies and measures the ETS was the preferred instrument for achieving the targeted CO_2 reductions, because such an approach can help reduce the cost to the European Community of meeting its commitments under the Kyoto protocol. In 2005 the European Union (EU) initiated the first phase of an emissions trading scheme (ETS) covering some 11,500 emitters and approximately 45% of the Carbon Dioxide (CO_2) emissions of the 25 EU member states. This scheme represents the first large scale CO_2 emissions trading program, in a region that accounts for some 20 percent of global GDP, and around 17 percent of global energy related CO_2 emissions (Ellerman and Buchner 2007). Directive 2003/87/EC of the European Parliament sets out the legal framework for the formation of the EU ETS (European Commission 2003). In a recent review of the EU ETS, European Commission (2006a) has, among other things, announced an assessment of the situation of smaller emitters. A working group has been established with a task to examine the costs and benefits of including small installations in the EU ETS with the aim to recommend a carbon emission threshold below which installations would not be forced into the ETS, but would have a choice to opt-in. The Commission foresees that the emissions of the installations that choose to stay out of an ETS will be regulated through other policies and measures (European Commission, 2006a).

Despite the focus on EU ETS, both the theoretical and empirical results reported in this paper are of general relevance for carbon emissions trading systems, and can inform governments that are currently considering establishing an ETS—such as the Australian government—of the tradeoffs involved with the coverage of smaller or larger number of emitters in an ETS.

The paper proceeds as follows. In the next section, the refined conceptual model of an optimal coverage of installations in an ETS is outlined. The following section reports the data and methods used to conduct the empirical analysis. The results from the empirical analysis together with a discussion are reported in the penultimate section. In the final section, some conclusions are derived and policy implications are discussed.

Conceptual framework

The question of coverage of installations in an ETS is conceptualised through the perspective of a regulator whose objective is to achieve an exogenously set CO_2 emissions reduction target at a minimum cost. The pertinent assumption is that the regulator has only two instruments at their disposal: either to use an emissions standard, or to set-up an emissions trading system. This assumption is only needed for the purpose of keeping the analysis focused, and can be easily relaxed to include other instruments (e.g. taxes). In order to determine the optimal level of coverage under the ETS, the regulator has to evaluate the aggregate benefits and costs for both the ETS and the emissions standard.

Cost of coverage by an ETS

The cost of participation in an ETS for an individual installation, assuming free initial allocation of emissions allowances (i.e. grandfathering)[2], can be expressed as:

$$TC_{ij}^{ETS} = TAC_{ij}^{ETS} + TRC_{ij}^{ETS}, \qquad (1)$$

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[2] Convery and Redmond (2007) describe the principal approach to emission allowance allocation in the EU ETS as one involving a free or ‘grandfathered’ allocation based on a reduction below the projection of business-as-usual emission levels for a given installation during the period covering the first phase of the EU ETS.

where: TC_{ij}^{ETS} is the total cost accruing to installation *j* in industry *i* from participation in the ETS, TAC_{ij}^{ETS} is the total abatement cost of the installation under the ETS, and TRC_{ij}^{ETS} is the total cost of administration, monitoring and other regulatory costs.

It is possible to further decompose the total cost of abatement into its constituent parts:

$$TAC_{ij}^{ETS} = \int_{E_{ij}}^{q_{ij}} MAC_{ij}(E_{ij})dE_{ij} - Pe_{ij} \cdot (E_{ij}^{ST} - E_{ij}), \qquad (2)$$

where MAC_{ij} is the marginal abatement cost for installation *j* in industry *i*, q_{ij} is the unregulated level of emissions for installation *j* in industry *i*, E_{ij} is the choice of emission level for that installation, Pe_{ij} is the market price of emission allowances faced by that installation, E_{ij}^{ST} is the initial allocation of allowances to the installation.

The effective price of allowances faced by any installation is the sum of the prevailing market price and the cost of transaction to purchase or sell that permit; for buyers of allowances transactions cost add to the effective price of allowances, and for sellers they detract from the price received[3]. This can be expressed by:

$$Pe_{ij} = Peq \pm t_{ij}, \qquad (3)$$

where Peq is prevailing market price for emission allowances, and t_{ij} are installation specific transactions cost of buying and selling allowances.

Additionally, the total regulatory cost (*TRC)* prevailing under either the ETS or the standard can be expressed as the sum of regulatory cost generated at the installation, R_{ij} and the costs of oversight and regulation generated by the government regulator which

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[3] An extended model of transaction costs can be found in Grafton *et al* (2004), pp. 78-79.

are passed onto the installation, GR_{ij}. Such that; total regulatory cost under the ETS can be expressed as:

$$TRC_{ij}^{ETS} = R_{ij}^{ETS} + GR_{ij}^{ETS}, \qquad (4)$$

and that under the emission standard can be expressed as:

$$TRC_{ij}^{ST} = R_{ij}^{ST} + GR_{ij}^{ST}, \qquad (5)$$

Cost of coverage by an emission standard

The cost of compliance for an individual installation covered by an emission standard as opposed to being covered with an ETS, and can be expressed as:

$$TC_{ij}^{ST} = TAC_{ij}^{ST} + TRC_{ij}^{ST}, \qquad (6)$$

where TAC_{ij}^{ST} is the total abatement cost for installation *j* in industry *i* under the standard, and TRC_{ij}^{ST} are the costs of administration, monitoring and other costs imposed by the regulation.

The total abatement cost under the standard can be represented as:

$$TAC_{ij}^{ST} = \int_{E_{ij}^{ST}}^{q_{ij}} MAC_{ij}\left(E_{ij}\right) dE_{ij}, \qquad (7)$$

where E_{ij}^{ST} is the allowable amount of emissions set out by the standard, q_{ij} is the unregulated level of emissions for installation *j* in industry *i*, E_{ij} is the choice of emission level for that installation, which is expected to correspond to E_{ij}^{ST} if the standard is binding.

Benefits of coverage by an ETS

The benefits that an individual installation *j* in industry *i* derives from being included in an ETS, compared to being regulated by a standard, can be represented as the difference between the total abatement costs under the standard (equation 5) and the total abatement cost under the ETS (equation 2):

$$B_{ij}^{ETS} = TAC_{ij}^{ST} - TAC_{ij}^{ETS}, \tag{8}$$

where B_{ij}^{ETS} denotes the benefits from being covered in an ETS for installation (*j*) in industry (*i*). The aggregate social benefit of having an ETS compared to having a standard can be expressed as:

$$B_{n}^{ETS} = TAC_{n}^{ST} - TAC_{n}^{ETS} = \sum_{j=1}^{n} TAC_{j}^{ST} - \sum_{j=1}^{n} TAC_{j}^{ETS} \quad , \tag{9}$$

where B_{n}^{ETS} is the aggregation of benefits accruing to the *n* installations covered by the ETS. As the number of installations covered in the ETS is varied, the value of the aggregate benefits changes. A concave benefit function whose argument is the number of installations covered in an ETS is needed to represent this situation. The function is required to have the following properties $\Delta B / \Delta n > 0$ and $\Delta^2 B / \Delta n^2 < 0$ such that an interior net benefit maximisation can be achieved across the range of potential installation inclusions.

Aggregate cost of an ETS

The difference in cost of compliance between the ETS and the emission standard at an individual emitter level can be expressed by:

$$C_{ij}^{ETS} = TRC_{ij}^{ETS} - TRC_{ij}^{ST} \quad , \tag{10}$$

where C_{ij}^{ETS} denotes the costs of administration and monitoring, imposed on an installation that is covered with an ETS, compared to a standard.

At an aggregate level, the total regulatory costs arising from participation in the ETS for n installations can be expressed as the sum of individual costs for installations:

$$C_n^{ETS} = \sum_{j=1}^{n} \left(TRC_j^{ETS} - TRC_j^{ST} \right). \tag{11}$$

The optimal coverage of installations in an ETS can then be derived by maximising the difference between the schedule of aggregate benefits (Eq. 8) and those of aggregate costs (Eq.9). This corresponds to the level at which net benefits are maximised. To put it in terms of marginal value, the optimal coverage will be achieved where the marginal benefit of adding another installation to the ETS, will be just equal to the marginal administration and monitoring costs of adding that installation. Employing equations (8) and (10), this can be expressed as:

$$\frac{\Delta B_n^{ETS}}{\Delta n} = \frac{\Delta C_n^{ETS}}{\Delta n} \tag{12}$$

The value for n that satisfies this equality determines the optimal number of installations from a given industrial sector to be covered in an ETS. This is graphically represented in figures 1 and 2. The level of optimal coverage is given by the point where the marginal benefits are equated to the marginal costs. This is also consistent with the point at which net benefits are maximised (Figure 2).

Data

Several sources of data were utilised to conduct an empirical analysis along the lines of the conceptual framework proposed above. Installation-level data on verified emissions and allowance allocations for 2005 were used for the EU ETS. Data were published in the Community Independent Transaction Log (CITL). Data consisted of observations on allowance allocations and verified emissions for 9,847 installations in 23 EU member states. The installations were grouped in eight industrial sectors: Cement and lime, Ceramics, Combustion (installations with installed capacity of more than 20 megawatts), Glass, Iron and steelworks, Pulp and paper, Refineries, and unclassified sector of other installations.

Data on cost of abating CO_2 emissions were very difficult to obtain, due to limited amount of information available in the literature, and the confidentiality of abatement cost information. Nevertheless, several literature sources were identified where abatement cost data were reported. A meta analysis of these data was than put together in an attempt to derive an empirical marginal abatement cost function for several industrial sectors. This was done for seven of the industrial sectors represented in the EU ETS data: Cement and lime, Ceramics, Combustion, Glass, Iron and steelworks, Pulp and paper, and Oil refineries.

Abatement cost data for cement and lime sector

In the EU ETS data, the cement and lime sector is represented by 472 installations, emitting on aggregate approximately 169.5 million tonnes of CO_2 sector wide annually. The manufacture of cement and lime represents a significant contribution to EU emissions of CO_2 due to the energy intensity of the manufacturing process and the evolution of CO_2 during the chemical transition of the raw materials to cement and lime. De Beer *et al.* (2001), Cembureau (1999) and Anderson and Newell (2003) suggest that there is scope to improve the energy efficiency of cement manufacturing, substitute fossil fuels with waste products to fire the kilns, modify the composition of the cement by reducing clinker content of finished product, and adopt techniques of carbon capture and storage. Based on the estimates provided in these literature sources, Appendix table 2 presents the derived schedule of abatement cost and abatement potential for the installations in the cement and lime sector.

Abatement cost data for the ceramics sector

In the EU ETS data, the ceramic sector is represented by 1010 installations, emitting on aggregate approximately 13.4 Mt of CO_2 annually. De Beer *et al.* (2001) and the European Commission (2006c) suggest that the scope for reductions of CO_2 emissions in the ceramics sector are limited to the improvement in the design of kilns and dryers, and the enhanced recovery and recycling of heat across the production process. Based on the estimates provided in these literature sources, Appendix table 3 presents the derived schedule of abatement cost and abatement potential for the installations in the ceramics sector.

Abatement cost data for the combustion sector

In the EU ETS data, the combustion sector is represented by 6274 installations, emitting on aggregate approximately 1348 Mt of CO_2 annually. Hendriks *et al.* (2001) and the European Commission (2006b) suggest that substantial scope exists to reduce CO_2 emissions through the substitution of existing fuel sources with those which generate less CO_2 per MWh of output, increasing the efficiency of fuel conversion, employing renewable energy technologies, and adopting carbon capture and storage techniques. Based on the estimates provided in these literature sources, Appendix table 4 presents the derived schedule of abatement cost and abatement potential for the installations in the combustion sector.

Abatement cost data for the glass sector

In the EU ETS data, the glass sector is represented by 372 installations, emitting on aggregate approximately 19 Mt of CO_2 annually. De Beer *et al.* (2001) and the European Commission (2001c) suggest that opportunities to reduce CO_2 emissions are limited to reducing energy consumption through improved melting technique and furnace design, increasing the percentage of recycled glass used in the production process, and increasing the recovery and recycling of heat across the production process. Based on the estimates provided in these literature sources, Appendix table 5 presents the derived schedule of abatement cost and abatement potential for the installations in the glass sector.

Abatement cost data for the iron and steel sector

In the EU ETS data, the iron and steel sector is represented by 220 installations, emitting on aggregate approximately 133 Mt of CO_2 annually. De Beer *et al.* (2001), European Commission (2001b) and Anderson and Newell (2003) suggest that there is scope to reduce CO_2 emissions by substituting coal, oil or biomass for up to 30 percent of the coke requirements in the blast furnace, recycling waste heat from the blast furnace to other sections of the production process, and by adopting techniques of carbon capture and storage. Based on the estimates provided in these literature sources, Appendix table 6 presents the derived schedule of abatement cost and abatement potential for the installations in the iron and steel sector.

Abatement cost data for the pulp and paper sector

In the EU ETS data, the pulp and paper sector is represented by 761 installations, emitting in aggregate approximately 29.8 Mt of CO_2 annually. De Beer *et al.* (2001) and European Commission (2001a) suggest that the pulp and paper sector may approach reductions in CO_2 emissions through the adoption of co-generated heat and power facilities, energy capture from the emissions optimised incineration and solid waste, and by the recovery and recycling of heat throughout the production process. Based on the estimates provided in these literature sources, Appendix table 7 presents the derived schedule of abatement cost and abatement potential for the installations in the pulp and paper sector.

Abatement cost data for the oil refining sector

In the EU ETS data, the oil refining sector is represented by 149 installations, emitting in aggregate approximately 147 Mt of CO_2 annually. Hendriks *et al.* (2001) suggests that reductions in CO_2 emissions could be achieved by adopting improved distillation techniques such as reflux overhead vapour recompression, employing more efficient process catalysts, and the installation of co-generated heat and power facilities. De Beer *et al.* (2001) and Anderson and Newell (2003) suggest that additional CO_2 abatement approaches may include the capture and recycling of high pressure and heat to other stages in the refining process, and the adoption of carbon capture and storage techniques.

Based on the estimates provided in these literature sources, Appendix table 8 presents the derived schedule of abatement cost and abatement potential for the installations in the oil refining sector.

Administration, monitoring and transactions cost

The data on the cost of administration, monitoring, transacting in allowances, and other regulatory costs, were also very difficult to obtain. Again, some literature sources were used to compile a data set of these costs. In an attempt to define administrative and monitoring costs Betz (2005) investigates the case of German installations covered in the EU ETS, finding that ongoing administration and monitoring costs, before active market trading occurs for an average installation amounts to approximately €28,000 per year. This is composed of the sum of costs incurred for risk management, monitoring and reporting of emissions and verification costs, and the accounting of allowances in balance sheets. Ongoing administration and monitoring costs are assumed to be invariant between installations regardless of the volume of emissions or allocation of emission allowances. These costs can be viewed from the installations pint of view as fixed costs. In addition to these costs, Betz (2005) notes that the German government incurs ongoing costs of oversight and regulation of the ETS, which amounts to €7,453,000 per annum for the 1849 installations covered, which represents an average cost of around €4000 per installation, and places the sum of administration, monitoring and government costs for an average installation covered in the ETS at €32,000. Betz and Ancev (2006) identify that the corresponding installation administration and monitoring costs if covered by an emissions standard are estimated at approximately €17,000, as they include only monitoring, reporting and verification costs. The government incurred costs of oversight and regulation are unknown, but are expected to be less on per installation basis than the same costs incurred under an ETS (€4000 per installation). Based on these data, in the ensuing empirical model it will be assumed that the government incurred costs of oversight and regulation are approximately the same regardless of whether the installation is covered in the ETS or the standard. Overall, for the purpose of the empirical analysis, the TRC_{ij}^{ETS} (Eq. 4) is set to €28,000 and TRC_{ij}^{ST} (Eq. 5) is set to €17,000.

Method

Cost Structure and Functional Form of Abatement

In choosing a functional form to describe the abatement cost structure of the selected industrial sectors there are several desirable properties that need to be satisfied by the chosen functional form. Bohringer *et al.* (2004) suggest that the choice of functional form should yield a marginal abatement cost (MAC) of zero at a given baseline (unregulated) emission level. Stavins (1995) notes that in the process of reaching an abatement target at a minimum cost under an ETS, the MACs should be equated between installations that carry out positive levels of abatement. For this to occur there is a need for a MAC function to be convex and increasing in abatement across the full range of abatement. analytically this can be represented through the following properties: $\frac{\partial MAC}{\partial A} > 0$, and $\frac{\partial^2 MAC}{\partial A^2} > 0$, where A is the quantity of abatement (tons of C02, in this case).

Bohringer and Loschel (2003) identify several common functional forms that satisfy these basic criteria, including iso-elastic functional form: $MAC = \alpha(A)^{\beta}$, quadratic functional form: $MAC = \alpha A + \beta A^2$, and the two exponential functional forms: $MAC = \alpha \exp\left(\beta\left(\frac{A}{e_0}\right)\right)$ and $MAC = \alpha(\exp(\beta A) - 1)$, where A is the number of units of emissions abated and e_0 is the baseline emission level. The latter of these ($MAC = \alpha(\exp(\beta A) - 1)$) was chosen for the purposes of the empirical analysis.

The rationale for this choice of functional form was that it satisfied the desirable properties described above, and because it can be easily manipulated to express the total abatement cost. In addition, the parameters of the function (α and β) can be meaningfully interpreted.

The total abatement cost is given by the integration of the MAC expression with respect to A, such that the total abatement cost (TAC) for this particular functional form can be expressed as:

$$TAC = \frac{\alpha}{\beta}(\exp(\beta A) - 1) - \alpha A, \tag{13}$$

where the constant of integration *(c)* was eliminated by recognising that when the abatement level is zero.

In addition, abatement *(A)* can be defined as the difference between the baseline level of emissions *(e_0)* and the choice of emissions under regulation *(e)*, which can be expressed:

$$A = e_0 - e$$

Substituting this expression into MAC and TAC expressions give:

$$MAC = \alpha\{\exp(\beta(e_0 - e)) - 1\}, \tag{14}$$

$$TAC = \frac{\alpha}{\beta}\{\exp(\beta(e_0 - e)) - 1\} - \alpha(e_0 - e), \tag{15}$$

Generating Abatement Cost Function Estimates

To simulate the heterogeneity between installations within a singe sector, it was assumed that each of the seven considered sectors is composed of four installations representative of the various levels of CO_2 emissions. Each of these four installations represents a quartile of the recorded CO_2 emissions for a given sector. This effectively amounts to classifying installations into representative groups of small, medium, large, and very large emitters within the industrial sectors. The data on quartiles of CO_2 emissions for the seven industry sectors from EU ETS are presented in Table 1.

Given the marginal abatement cost (MAC) functional form specified in equation (15) and the installation specific baseline CO_2 emissions values, it was possible to estimate the installation specific values of the parameters of the MAC function, α and β. The parameters were estimated using ordinary least squares so that the MAC function was fitted through the abatement cost data (reported in Appendix tables 2-7) by minimising the sum of the squares. This was done by specifying an objective function corresponding to the sum of squares, and minimising it by varying the values for the parameters (α and β) for each of the four representative installations in each industrial sector. The minimisation algorithm was run using the EXCEL computer software.

Because sectoral abatement estimates were presented in percentages of total sector emissions, it was assumed that an individual installation can abate the same percentage of its own emissions at the same costs as it can be done at a sectoral level. For example, any installation in the oil refining sector can abate 8 % of its CO_2 emissions for between € 0 – 10 per tonne, and a further 65 % for between € 190 – 200 per tonne.

Simulating alternative coverage scenarios

Once the parameters of the marginal abatement cost functions for the representative installations in the industrial sectors were obtained, it was possible to evaluate the costs and benefits of each individual installation being covered under an ETS, as opposed to the same installation being covered by an emissions standard. This was done by invoking the analytical expressions derived in the theory section, with a specific aim to identify the number of installations n that maximises the difference between the aggregate benefits (Eq. 9) and the aggregate cost (Eq. 11). To determine the effect of the stringency of a cap for the tradable permit system—which directly corresponds with the stringency of an emissions standard—four alternative aggregate CO_2 reduction targets were simulated: 10% decrease in aggregate CO_2 emissions, 20% decrease, 30% decrease, and 40% decrease in aggregate CO_2 emissions. For each of these reduction targets, three scenarios were simulated: Scenario 1, where all installations were covered by the ETS; Scenario 2, where all installations are covered by an emissions standard; and Scenario 3, where the coverage of the installations in each of the sectors by an ETS was determined according to the optimality criteria derived above (Eq. 12).

Results

The estimates of the parameters of the marginal abatement cost functions for the representative installations across sectors are given in Table 2. The parameter estimates for the marginal abatement cost functions by installation and by sector reported in table 2 suggest that there is some positive correlation between the values for β and the baseline emissions values. This is likely attributable to the assumed homogeneity of abatement technology available to installations within a given sector, which has resulted in the marginal abatement cost being equalised between installations in a given sector when they undertake the same level of abatement in percentage terms. This suggests that by construction, the installations within a given sector share common marginal abatement cost elasticities across their full range of emissions. From equation 15, the elasticity of the marginal abatement cost can be expressed as:

$$\varepsilon_{MAC} = \frac{\beta(e_0 - e)\exp\{\beta(e_0 - e)\}}{\exp\{\beta(e_0 - e)\} - 1}. \tag{16}$$

For a very large emitter, a given percentage reduction in emissions will result in larger values of $e_0 - e$ than for a smaller emitter undertaking the same percentage reduction in emissions. In order to maintain the equality in the elasticity of marginal abatement cost across installations within a sector, the value of β must be relatively smaller for very large emitters than for smaller emitters.

The estimated values for the α parameter for installations within a given sector are very similar, reflecting the common possibilities and costs of abatement among installations of the same sector. This can be attributed to the use of the same abatement technology. However, the estimated values for α vary significantly between sectors, which reflects the differences in abatement technologies applicable to individual sectors. As α performs a multiplicative role in the MAC function, smaller values of α indicate a greater potential for abatement at any given level of marginal cost. In general, higher values of α are associated with sectors where relatively little abatement opportunities exist, such as glass or ceramics sectors, while smaller values are associated with those sectors which have ample abatement opportunities at their disposal, such as oil refining or combustion sectors. This suggests that the parameters α and β indicate some of the salient characteristics of inter and intra sectoral abatement possibilities.

Results from the three simulated scenarios under the four alternative aggregate CO_2 reduction targets are reported in Table 3. There are several observations that can be made from these results, which broadly support the theoretical proposition that an optimal level of inclusiveness in an emissions trading system is likely to be more cost-effective than a blanket coverage of all installations. The first point to note is that at each level of aggregate reduction targets, the scenario using the optimality conditions as criteria for coverage of installations in ETS resulted in the lowest total cost of achieving the specified reduction target. This result emphasises the cost-effectiveness of the partial coverage of installations in comparison to the blanket coverage.

An additional observation is that in the case of the 10% reduction target the total cost estimates suggest that a blanket coverage of installations with an emissions standard is superior in terms of cost-effectiveness compared to the blanket coverage with an ETS. This reflects the small potential gains from trade, in comparison to the additional costs of administration, transaction and monitoring that comes with the coverage of installations in an ETS. This suggests that if the regulator has insufficient knowledge about the sector specific abatement costs, and can only adopt one policy instrument, then at low levels of required aggregate abatement, an emissions standard might be more cost-effective than an ETS.

Another prominent observation from the results is the relationship between the optimal level of coverage of installations with a given policy instrument, and the stringency of the aggregate emissions reduction target. In principle, the optimal level of coverage of installations by an ETS increases with the increased level of stringency of reduction targets. This can be attributed to the differences in aggregate abatement costs under an ETS, and under an emissions standard, when the stringency of reduction targets is increasing. The implication is that the benefits accruing to each installation covered in an ETS—which originate in the difference between abatement costs—increase for all installations with ever more stringent reduction targets. As the cost of administration and monitoring are static and do not change with the stringency of the target, the growing benefits of having an ETS outweighs these costs, and hence the aggregate net benefit from including installations in an ETS are quite high.

Summary and Conclusion

The question of how to design an emissions trading scheme in relation to its coverage of installations is one of the key design issues that regulators across the world will have to address as they set up tradable permit systems for CO_2. This paper provides conceptual and empirical insights on this issue.

From a conceptual perspective, it was important to identify the key elements of the criteria for optimal level of coverage of installations in an ETS. Not surprisingly, these key elements turn out to be the benefits and the costs, both in total and at the margin, that can be attributed to covering installations in an ETS,. The more challenging task that this paper undertook was to represent benefits from coverage of installations with an ETS as the difference in the cost of abatement under ETS and under an alternative policy instrument designed to reduce GHG emissions, in this case an emissions standard. In addition, the costs of implementing policy instruments were broken down to cost of abatement, cost of administration, monitoring and compliance, and transactions cost. This kind of conceptual representation enabled the derivation of optimality conditions for optimal coverage of installations in an ETS, which stated that an installation should be covered in an ETS as long as the marginal benefits of doing so exceed the marginal cost. Following this criterion would ensure maximum net social benefit from an ETS.

The empirical work presented in the paper supported these conceptual findings, and showed that blanket coverage of installations in an ETS is inferior to the coverage according to the optimality criteria. The empirical study conducted was rather challenging, due to several reasons. One was that the data on allocation allowances and emissions for the EU ETS were only available for one year (2005). Data covering longer time periods would enable better estimation of abatement quantities in relation to the baseline level, and would therefore improve the accuracy of abatement cost estimates. In addition, data on cost of reducing CO_2 were very limited, and the study had to rely on a handful of literature sources for the abatement quantity data. Again, this likely compromises the accuracy of marginal abatement cost estimates. Further, the challenging issue of the choice of functional form for marginal abatement cost function had to be dealt with, keeping in mind the desirable properties to be exhibited by the function, its tractability and computational limitations imposed by the choice of the functional form, as well as the possibility for interpretation of the parameters of the function. These challenges and shortcomings were overcome by invoking certain assumptions. Nevertheless, the level at which the assumptions were made ensured that the derived results are not driven by those assumptions, but are representative of the real economic forces at play.

The results from the empirical study confirmed the hypothesis that blanket coverage of installations in an ETS is not likely to be a cost-effective policy. In all but one of the simulated scenarios—where the costs were the same— blanket coverage was a more costly option compared to the optimal coverage of installations. Dependent on the desired level of emission reduction, the optimal coverage of installations varies. In particular, for relatively small emission reduction targets (e.g. 10%) the difference between blanket coverage and optimal coverage was rather notable. For more ambitious reduction targets, the costs difference between the two options is diminished.

Problematically, the information requirement in identifying the optimal coverage level presents a potentially significant practical impediment to achieving a socially optimal outcome. The results of the empirical analysis suggests that there is some scope for ‘savings’ to be achieved in applying the optimality criterion, which may provide the incentive for investment in the collection of data regarding abatement potentials and costs of installations which could be targeted in the establishment of an ETS.

Regulators around the world are currently contemplating the possibilities for designing national emissions trading systems, as cost-effective instruments to reduce greenhouse gas emissions. In the process, they are confronted with numerous challenging design issues. The coverage of installations in an ETS is one such design issue. While blanket coverage that includes most industrial emitters of CO_2 in an economy (such as

EU ETS) has some intuitive appeal, and seems equitable, it does not take into full account the cost and benefits of coverage. This paper shows that an alternative coverage rule based on satisfying the criterion of maximising the benefits from inclusion of installations in an ETS provides the same emission reduction outcome at lower cost. This implies that regulators should be looking very carefully at given industrial sectors and should be trying to determine an optimal number of installations to be covered with an ETS. Such an approach is going to be less costly than an approach where installations are compulsory covered in an ETS across the board. Since this paper has been focusing on an downstream approach only, future work may be including the upstream approach and give guidance on the cut-off criteria between downstream or upstream coverage. This might be particularly relevant in the Australian context, for which a hybrid coverage is likely.

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Table 1. Representative small, medium, large, and very large installations from each covered sector, with emission levels reported in kilo tonnes (kt) per annum

Sector	Small Installation (kt of CO_2 emissions)	Medium Installation (kt of CO_2 emissions)	Large Installation (kt of CO_2 emissions)	Very Large Installation (kt of CO_2 emissions)
Cement and lime	48.54	218.62	544.79	2864.43
Ceramics	4.51	9.00	16.94	154.50
Combustion	4.62	14.85	52.66	10028.47
Glass	15.24	34.47	72.84	592.75
Iron and steelworks	25.64	57.06	144.64	11534.47
Pulp and paper	6.59	18.40	43.22	421.19
Oil refining	157.69	574.11	1520.57	6266.75

Table 2. Estimates of the parameters of the marginal abatement cost functions for the representative installations

Sector	Small Installation		Medium Installation		Large Installation		Very Large Installation	
	alpha	beta	alpha	beta	alpha	beta	alpha	beta
Cement and lime	1.0734	0.1476	1.0732	0.0328	1.0732	0.0132	1.0731	0.0025
Ceramics	5.0357	1.6878	5.0357	0.8462	5.0357	0.4498	5.0357	0.0493
Combustion	1.4545	1.5430	1.4545	0.4802	1.4545	0.1354	1.4545	0.0006
Glass	4.6975	0.4277	4.6975	0.1891	4.6975	0.0895	4.6974	0.0110
Iron and steelworks	1.0300	0.2618	1.0300	0.1176	1.0300	0.046	1.0297	0.0006
Pulp and paper	3.9818	0.9449	3.9818	0.3382	3.9818	0.1440	3.9818	0.0148
Oil refining	1.3413	0.0323	1.3413	0.0089	1.3413	0.0033	1.3413	0.0008

Table 3. Estimated total cost (including cost of abatement and cost of compliance) under three simulated scenarios and four emission reduction targets

Aggregate Emissions Reduction (%)	Scenario 1: All covered by ETS	Scenario 2: All covered by ST	Scenario 3: Optimality criteria		
	TC^{ETS}	TC^{ST}	TC^{opt}	Number of installations in ETS	Number of installations in ST
10	€2,720,869.36	€2,618,864.54	€2,553,105.47	3	25
20	€10,795,789.18	€11,608,672.90	€10,712,273.55	14	14
30	€30,611,610.38	€33,984,258.23	€30,595,837.78	25	3
40	€72,003,325.73	€82,170,440.11	€72,003,325.73	28	0

Figure 1: Benefit and Costs of Coverage in the ETS

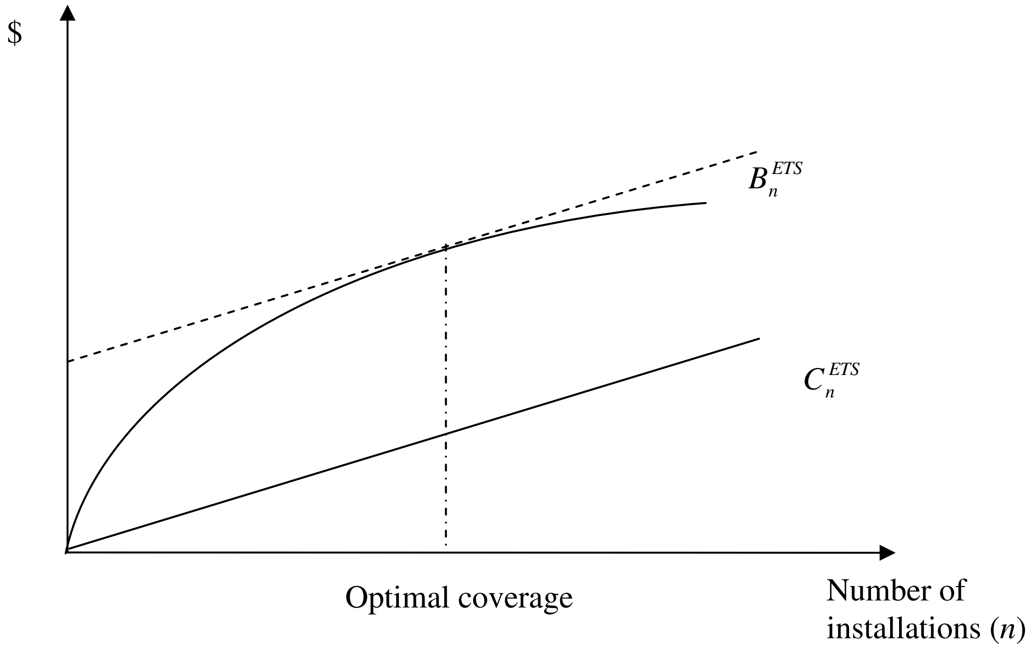
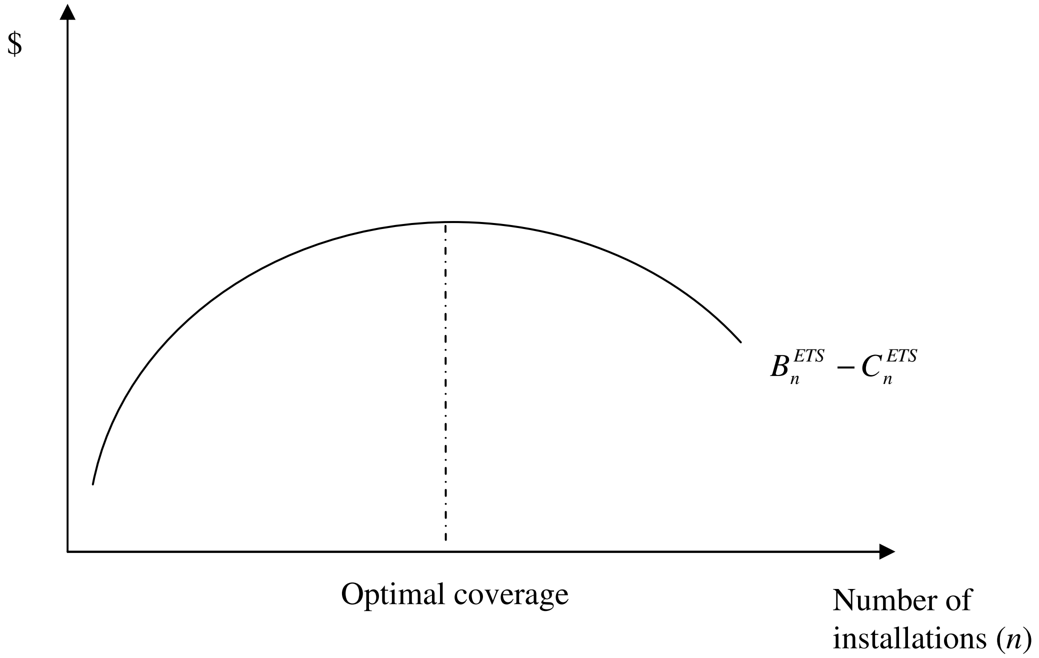


Figure 2: Net Benefits of Coverage in the ETS



Appendix

Appendix table 1: Representative installations ranked by baseline emission level

Installation	Baseline Emissions Value (Kt)	Sector
1	12,497.63	Combustion
2	11,534.47	Iron and Steel
3	6,266.75	Oil Refinery
4	2,864.43	Cement and Lime
5	1,520.57	Oil Refinery
6	592.75	Glass
7	574.11	Oil Refinery
8	544.79	Cement and Lime
9	421.19	Pulp and Paper
10	218.62	Cement and Lime
11	157.69	Oil Refinery
12	154.50	Ceramics
13	144.64	Iron and Steel
14	72.84	Glass
15	57.06	Iron and Steel
16	52.66	Combustion
17	48.54	Cement and Lime
18	43.22	Pulp and Paper
19	34.47	Glass
20	25.64	Iron and Steel
21	18.40	Pulp and Paper
22	16.94	Ceramics
23	15.24	Glass
24	14.85	Combustion
25	9.00	Ceramics
26	6.59	Pulp and Paper
27	4.62	Combustion
28	4.51	Ceramics

Appendix table 2: Cement and Lime Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Reducing clinker content of cement, wastes and biomass as fuels, heat recovery from clinker cooler, application of multi-stage pre-heaters and pre-calciners	0 – 10	8
Carbon Capture and Storage	190 - 200	65

Source: De Beer et al. (2001); Cembureau (1999); Anderson and Newell (2003)

Appendix table 3: Ceramics Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Improved kilning techniques and furnace design, heat recovery and recycling	0 – 10	15

Source: De Beer et al. (2001); European Commission (2006c)

Appendix table 4: Combustion Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Biomass, Onshore Wind Energy, Replacement of coal-fired capacity by natural gas-fired Combined Cycle	0 – 10	31
Biomass, Hydro electric (>10MW)	10 – 20	6
Geothermal	50 - 60	0.1
Offshore Wind Energy	80 - 90	1
Tidal energy	110 - 120	0.1
Carbon Capture and Storage	190 - 200	30

Source: Hendriks et al. (2001); Anderson and Newell (2003); European Commission (2006b)

Appendix table 5: Glass Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Raising the percentage recycled glass in input materials, raw material and recycled glass pre-heating, improved melting technique and furnace design	0 – 10	15

Source: De Beer et al. (2001); European Commission (2001c)

Appendix table 6: Iron and Steel Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Coal substituting for Coke up to 30%, Application of continuous casting, Scrap pre-heating, Oxygen Injection	0 – 10	7
Recovery of process gases from blast furnaces	30 - 40	0.75
Recovery of heat from high temperature processes	130 - 140	0.75
Carbon Capture and Storage	190 - 200	70

Source: De Beer et al. (2001); European Commission (2001b); Anderson and Newell (2003)

Appendix table 7: Paper and Pulp Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Heat recovery, improved drying and pressing processes, fuel substitution	0 – 10	20

Source: De Beer et al. (2001); European Commission (2001a)

Appendix table 8: Oil Refining Sector Marginal Abatement Cost and Scope Estimates

Abatement Measure	Estimated Costs €/tCO2	Estimated Emission Reduction %
Process improvements i.e.: Reflux overhead vapour recompression, power recovery, improved catalysts	0 – 10	18
Combined Heat and Power generation	60 - 70	7
Carbon Capture and Storage	90 - 100	60

Source: De Beer et al. (2001); Hendriks et al. (2001); Anderson and Newell (2003)