Market-based emission performance standards in a multi-sector context: An assessment of Alberta's Specified Gas Emitters Regulation

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Abstract

In the policymaker's toolkit of instruments to reduce greenhouse gas (GHG)-related externalities, emission intensity targets appear a politically more palatable alternative to economist's prescriptions for carbon tax or emission targets. Although emission intensity standards (EIS) and more generally performance standards are common place, they are relatively scarce in the context of GHG emissions. In this paper, we analyze alternative designs of EIS in a multi-sector context and compare them to cost-effective policies. We also perform an empirical analysis assessment of the performance of one particular design of EIS that has been adopted in the Canadian province of Alberta, called the Specified Greenhouse gas Emitters Regulation (SGER). Comparing the EIS to carbon tax we show how the choice of the additional policy parameters of the EIS such as the penalty for non-compliance and the baseline relative to which the level of non-compliance is determined can allow policy-makers to design an EIS to approach

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cost-effectiveness. Analyzing the compliance data from regulated facilities to estimate the effect of the SGER, we discuss the heterogenous effect on actual onsite emissions, effective emissions,(which refers to emissions net of abatement achieved through the purchase of emission credits, offsets and penalty) and output in the different regulated sectors. Finally, we analyze the compliance strategies of the regulated facilities in different sectors to see if it provides evidence in support of the large literature on engineering estimates of abatement cost of GHG emissions from industrial sources.

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1 Introduction

In the policymaker's toolkit of policy instruments to reduce greenhouse gas (GHG)-related externalities, performance-based emission regulations such as targets for emission intensity reduction, with the intensity indexed either to the quantity of physical output or economic output, say value added or gross domestic product, represent an alternative to policies that target emissions either directly, say through an emission fee or a system of tradable emission permits, or indirectly by subsidizing cleaner substitutes, say through mandates or subsidies for renewable energy. An advantage of regulating emission intensity compared subsidizing renewable energy is that it allows for the exploitation of greater number of margins for pollution reduction. For instance, under EIS it would be feasible, up to a limit depending on the stringency of the target, to switch from coal to natural gas or simply use coal more efficiently both of which can reduce emissions. Furthermore, an EIS would lead to adoption of the more cost-effective renewable technologies. Such margins are unavailable under uniform renewable energy policies. However, policies that target pollution directly either through emission fees or tradable emission permits, are the cost-effective approach because they permit use of the maximum number of margins for abatement. For instance, simply reducing the quantity of output might not possible under EIS.[1]. Hochman and Zilberman (1978) show that the cost-effective approach of pollution fee or tradable pollution permits leads to less output, higher prices and less employment relative to emission standards, factors to which they attribute the popularity of the latter. More importantly, emissions are allowed to increase under an emission intensity standard. The greater political support for targets for GHG-intensity of an economy as opposed to emission targets from rapidly industrializing nations of the world and some industrialized nations in the international negotiations for global agreement on climate change is also attributable to such features of intensity-based targets relative to emission-based targets (Newell and Pizer, 2008).

Albeit less commonly encountered in the world of current policies motivated by climate change, intensity standards and more generally performance-based regulations have been a popular approach in several other contexts. These regulations take the form of targets for concentration of specific pollutants per unit of discharge or per unit of input, energy use efficiency per unit of output etc. (Helfand, 1991) In the United States, prominent examples of intensity-based regulations include, New Source Performance Standards (NSPS) that dictate the level of pollutant per unit of discharge from new industrial facilities[2], minimum energy efficiency standards for appliances and automobiles (first established under the Energy Policy and Conservation Act of 1975)[3], the approach used in the phase-down of lead in gasoline[4] and Renewable Portfolio Standards that dictate the share of electricity to be derived from renewable sources. A recent and prominent example of a GHG intensity standard is the California Low Carbon Fuel Standard, which mandates reduction in greenhouse gas (GHG) intensity of transportation fuels consumed in California. The US federal government is

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[1] When emission intensity is an increasing function of output, reducing output can contribute to reducing emission intensity. However, emissions policies allow exploitation of this margin even when emission intensity does not vary with output

[2] See http://www.epa.gov/compliance/monitoring/programs/caa/newsource.html

[3] See http://www1.eere.energy.gov/buildings/appliance˙standards/

[4] See http://www.epa.gov/history/topics/lead/02.html

reportedly also considering a regulation on GHG intensity of electric power plants under the provisions of the Clean Air Act.

With the exception of NSPS, the other examples of performance-based regulations mentioned above each target a narrow set of activities, while the NSPS although it applies to any new stationary source it regulates air and water pollutants whose damage is local or regional in scope. Since GHGs are global pollutant, the wider the ambit of the regulation, lower will be the cost of achieving any given level of emission reduction. However, for designing an GHG EIS at an economy-wide level, an added complexity relative to designing an emissions-based approach such as a pollution fee or tradable pollution permits, is that the former not only requires the selection of level of the policy but also requires the selection of an index of performance, say, economic output (say, measured as value-added or gross domestic product), or physical output. Since the marginal damage due to GHG emissions is independent of the type or location of the activity generating pollution, indexing to economic output would lead to less inefficiency relative to indexing to physical output, since different sectors producing different types of goods while provide different level of economic benefits per unit of output and will also differ in the marginal cost of abatement of pollution.[5].

In this paper, we perform an *in media res* assessment of a one-of-a-kind GHG emission intensity regulation called the Specified Gas Emitters Regulation (SGER)[6] being implemented in the province of Alberta, Canada. This regulation, adopted in 2006, requires that facilities, which emit more than 100,000 tonnes of greenhouse gases per year, and were in operation prior to the year 2000 reduce their emissions intensity by 12%, as of July 1, 2007. Facilities that became operational after 2000 are provided a gradually increasing annual targets for emission intensity reduction of their output that eventually amount to a 12% reduction.

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[5] A formal mathematical proof of the claim that the cost-effectiveness of EIS indexed to economic output is higher at worst the same when compared to EIS indexed to physical output is left for future version of the paper

[6] http://environment.alberta.ca/0915.html

Facilities that began operations after 2007, are exempted from requiring to reduce emission intensity for their first three years of operation. Each regulated facility can comply with the regulation in four different ways – i) they could reduce emission intensity at each facility or site; ii) purchase and retire emission credits generated by other regulated facilities that have exceeded their target; iii) purchase and retire verified emission credits generated by unregulated facilities within Alberta, and these are called as offset credits; or iv) pay a penalty of $15 per tonne of carbon dioxide emissions they failed to abate. The penalty payments are collected in Climate Change and Emissions Management fund that is used to support R&D and demonstration projects aimed at developing new GHG mitigation technologies. The quantity of emissions "owed" for which the penalty applies is computed as product of the difference between the actual emission intensity during a given year and the target emission intensity for that year and the output in the given year. The current regulation is considered as the first phase and is set to end in 2014. The targets and rules for the second phase are under deliberation.

A critical aspect of SGER is that by dictating a uniform target for emission intensity reduction for each regulated facility, it allows for different levels of performance for different facilities within a given sector. In other words, it does not strive to achieve a uniform level of of emissions performance within each sector, let alone a uniform level of emissions performance per unit of economic output economy-wide. That this is not a cost-effective approach is given based on basic economic intuition. The motivation of this paper is therefore not simply identify the sources of inefficiencies in the current design, but to glean general insights about the cost-effectiveness of reducing GHG emissions from industrial sources based on the compliance strategies of the regulated facilities that can allow us to predict the outcomes under alternative policy designs. For instance, for any given target level of facility emission intensity, a facility manager maximizing profits from his/her facility will choose the least cost compliance strategy. Given that one of the choices for compliance is to pay a fixed penalty per unit of "unabated" emissions, which is $15 per tonne of CO_2e, facilities would be unlikely to undertake abatement in excess of this upper bound. This accords an opportunity to verify prominent engineering-economic estimates of cost-effectiveness of carbon abatements such as the study by Creyts et al. (2007) of McKinsey & Company, which states there is potential for about of 0.6 to 0.8 gigatonne of CO_2e abatement at negative "lifecycle" cost through improvements to industrial processes, combined heat and power generation and efficiency improvements in electric power plants. They also note that despite being negative lifecycle cost, these projects might be capital intensive and so compete with projects with higher internal rate of return. A US National Academies (2010) report titled *Real Prospects for Energy Efficiency in the United States*, concludes that there is potential to save 3.9 quads in annual energy-usage using investments with an internal rate of return of 10% or higher.

We therefore analyze the impact of the regulation on emissions in different sectors and analyze the compliance strategy of facilities in different sectors to glean some general behavioral patterns and also verify engineering-economic estimates of the potential for cost-effective CO_2 abatement from industrial processes.

2 Theory

This section develops a simple partial-equilibrium framework to analyze different policies in terms of their cost-effectiveness vis-a-vis political economy. We aim to identify the conditions under which regulations on emission rates could achieve cost-effectiveness in an economy-wide or multi-sectoral context. To illustrate the fundamental differences in incentives under different schemes we assume perfectly competitive conditions in each of the regulated sectors and price-taking behavior in both the product and emission markets.

The cost of producing a quantity of output q is $C(q)$ with $C_q \geq 0$ and $C_{qq} \geq 0$. Let

$Z(q)$ and $D(Z)$ denote emissions from production and the monetary harm from emissions, with $H(Z) \geq 0$, $H_Z \geq 0$ and $H_{ZZ} \geq 0$. Let subscripts i and j denote a firm and a sector, respectively, and superscript t denote time. The output price faced by a firm in sector j is P_j.

2.1 Optimal policy

The problem confronting a social planner maximizing welfare, W, composed of consumer surplus net of production cost and environmental harm, can mathematically be represented as

$$\underset{q_{i,j}}{max}\ W = \sum_{j=1}^{J} \left\{ \int_0^{\sum_{i=1}^{N_j} q_{i,j}} D_j^{-1}(q)dq - \sum_{i=1}^{N_j} C_{i,j}(q_{i,j}) \right\} - H\left(\sum_{j=1}^{J} \sum_{i=1}^{N_j} Z_{i,j}(q_{i,j}) \right) \tag{1}$$

At the social optimum, $\dfrac{dW}{dq_{i,j}} = 0\ \forall\ i \in (1..N_j)$ and $j \in (1..J)$

$$\Rightarrow D_j^{-1}\left(\sum_{i=1}^{N_j} q_{i,j} \right) - \frac{dC_{i,j}}{dq_{i,j}} - \frac{dH}{dZ^*_{i,j}} \frac{dZ_{i,j}}{dq_{i,j}} = 0 \tag{2}$$

A firm i in sector j, facing a price of P_j and tax T per unit of emissions and maximizing profit, would solve the problem

$$\underset{q_{i,j}}{max}\ \Pi_{i,j} = P_j q_{i,j} - C_{i,j}(q_{i,j}) - TZ_{i,j}(q_{i,j}) \tag{3}$$

At the private optimum, $\dfrac{d\Pi_{i,j}}{dq_{i,j}} = 0$

$$\Rightarrow P_j - \frac{dC_{i,j}}{dq_{i,j}} - T\frac{dZ_{i,j}}{dq_{i,j}} = 0 \tag{4}$$

Comparing equations 2 and 4, and with $P_j = D_j^{-1}(\cdot)$, we can see that a tax $T^* = H_Z(Z^*)$ would achieve the social optimum through a decentralized approach. Alternatively, capping total emissions Z^* and instituting a system of tradable emission permits would also achieve the social optimum in a decentralized manner.

2.2 Cost-effective policies

Often, however, optimality is an impractical objective on account of insufficient information about marginal damages. An alternate objective frequently employed is to achieve a politically determined level of (improvement in) environmental quality or (reduction in) pollution. The economic challenge then becomes achieving the given target at least cost. Say, the planner's goal is to maximize net (economic) benefits (NB), composed of consumer surplus net of production cost, while ensuring emissions do not exceed $\overline{Z}_T$, which mathematically is,

$$\underset{q_{i,j}}{max}\ NB = \sum_{j=1}^{J}\left\{\int_0^{\sum_{i=1}^{N_j} q_{i,j}} D_j^{-1}(q)dq - \sum_{i=1}^{N_j} C_{i,j}(q_{i,j})\right\}$$

$$\text{such that} \sum_{j=1}^{J}\sum_{i=1}^{N_j} Z_{i,j}(q_{i,j}) \leq \overline{Z}_T$$

Using the Lagrangian approach to converting a constrained maximization problem to an unconstrained maximization problem, the planner effectively solves,

$$\underset{q_{i,j},\lambda}{max}\ L = \sum_{j=1}^{J}\left\{\int_0^{\sum_{i=1}^{N_j} q_{i,j}} D_j^{-1}(q)dq - \sum_{i=1}^{N_j} C_{i,j}(q_{i,j})\right\} + \lambda[\overline{Z}_T - \sum_{j=1}^{J}\sum_{i=1}^{N_j} Z_{i,j}(q_{i,j})] \qquad (5)$$

where, λ represents the shadow price on the emissions constraint.

At the extremum, $\dfrac{dW}{dq_{i,j}} = 0$ and $\dfrac{dW}{d\lambda} = 0$

$$D_j^{-1}\left(\sum_{i=1}^{N_j} q_{i,j}\right) - \frac{dC_{i,j}}{dq_{i,j}} - \lambda\frac{dZ_{i,j}}{dq_{i,j}} = 0 \forall\ i \in (1..N_j) \text{ and } j \in (1..J) \tag{6}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{N_j} Z(q_{i,j}) = \overline{Z}_T \tag{7}$$

Following our discussion of the optimal policy, we can infer that a tax $T^* = \lambda^*$ or a system of tradable emission permits with the total number of permits issues capped at $\overline{Z}_T$, would achieve the maximum total surplus for any given level emissions through a decentralized approach.

2.3 Political economic considerations within market-based environmental regulations

2.3.1 Policies targeting emission reduction

A political impediment to enactment of emission taxes is that they take too much revenue away from polluters who tend to have considerable political power (Felder and Schleiniger, 2002; Pezzey, 2003; Sterner and Höglund Isaksson, 2006). One approach to limiting revenue loss to polluters so as to improve the political feasibility of taxes while maintaining the incentives for long-run economic efficiency is to grant 'rebates' [7] on taxes on infra-marginal emissions. The equivalent strategy for a system of tradable emission permits (TEP) is to freely distribute emission allowances (a portion or the entire amount) as opposed to a pure auction of all the allowances. If Δ denotes the level of emissions exempted from tax or equivalently the emissions grand-fathered under a system of TEP, the profit maximization

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[7] Referred to variously in the literature as 'subsidies', 'exemptions', 'thresholds', or 'allowances'

problem of a private firm shown in Equation (3) now becomes

$$\underset{q_{i,j}}{max}\ \Pi_{i,j} = P_j q_{i,j} - C_{i,j}(q_{i,j}) - T[Z_{i,j}(q_{i,j}) - \Delta] \tag{8}$$

We can see that when Δ is not dependent on quantity produced, the profit maximizing condition resulting from Equation (8) above will be identical to Equation (4), which implies that such a rebate would not have any effect on firm behavior in the short-run. For long-run efficiency, the rebate should be designed such that it does not affect incentives for firm entry and exit (Pezzey, 1992; Farrow, 1995) . This necessitates that the rebate be treated as a property right and not be contingent on the incumbent firm maintaining a positive level of output, just as emission permits tend to be when grand-fathered (Pezzey, 2003).

Let $\Delta = \alpha_{i,j} Z_E^0$, where Z_E is in units of emissions and $\alpha_{i,j}$ is a scalar. We describe how different choices for $\alpha_{i,j}$ and Z_E^0 lead to different but equivalent policy formulations from a long-run efficiency or cost-effectiveness standpoint but result in different levels of revenue transfer from the private sector to the government.

- Case 1a : $\alpha_{i,j} = 0$: Pure Tax with no rebates or equivalently a system of Tradable Emission Permits (TEP) with 100% auctioning of capped emissions. Results in maximum revenue transfer from polluters to government.

- Case 1b: $\alpha_{i,j} = 1$ and $Z_E^0 = Z_i^0$, firm ‘i’s emissions in the base period: Tax with a lump-sum rebate on the entire emissions during the base period or equivalently a TEP scheme with complete grand-fathering of each firm’s emissions in the base period. Results in minimum revenue transfer from polluters to government.

- Case 1c: $0 < \alpha_{i,j} < 1$ and $Z_E^0 = Z_i^0$: Tax with a lump-sum rebate for a fraction of baseline emissions or equivalently a TEP scheme with partial grand-fathering and partial auctioning of permits. For instance, 50% of each firm’s baseline emissions being exempt or grand-fathered. Results in an intermediate level of revenue transfer from polluters to government relative to $1a$ and $1b$.

- Case 1d: $\sum_{i=1}^{N} \alpha_{i,j} = 1$ and $Z_E^0 = Z_T^0$, the total emissions of all firms in the base period: In this case each firm is tax exempted (or grand-fathered permits) a fraction of total emissions from all regulated firms in the base period, with the firm's share proportional to its output share, or emission share or any other similar criterion. This might result in some firms receiving a net positive lump-sum subsidy relative to their baseline emissions. This approach results in full redistribution of revenues to polluters and zero net transfer of revenues to government.

It is worth reiterating that when Δ is a property right of incumbent firms and independent of firm behavior then all the above approaches are equally efficient or cost-effective in the long-run.

2.3.2 Policies targeting emission intensity reduction

Rebates on infra-marginal emissions or grand-fathering of historical emissions notwithstanding, polluters may yet oppose policies aimed at reducing total emissions if such policies are likely to restrain growth in production even if they adopt the most environment friendly method of production and lead to higher foregone profits. For instance, regulated firms might be relying on local resources for production that are inherently more pollution intensive such as lower grade deposits of ores and minerals that are harder to extract and require processing. These concerns are amplified when regulated firms compete in an international market and firms outside the jurisdiction are exempt from similar levels of regulation and, which are more justifiable in the context of global pollution to which regulated firms contribute a small share.

One response to such concerns is for policymakers to target reduction in emission intensity as opposed to reducing emissions. Although traditionally emission intensity standards have not allowed for trading in pollution credits, they are increasingly becoming market-based. An early example is the phase down lead in gasoline in the US which was instituted in 1980. A more recent example is the California Low Carbon Fuel Standard which mandates a GHG intensity target for transportation fuels sold within California. The US federal Corporate Fuel Economy Standards allow trading in energy efficiency credits across different models of automobiles produced within a single firm.

A benefit of a tradable emission intensity standard (TES) is it avoids the need for deriving a politically acceptable allocation of emission credits as the quantity of credits is endogenous. This benefit is somewhat mitigated by the complexity of TES in a multi-sectoral context for a common standard might be impractical for different sectors engaged in producing different types of goods at widely different emission rates. That said, one could argue the same political economic considerations influencing the distribution of permits across sectors would influence the selection of appropriate emission performance targets for each sector. A sector that is set a relatively weaker cap on emissions under a TEP could be expected to set a relatively less stringent target for emissions performance.

The tradability of the credits provides an incentive for firms to exceed the standard, lowering the price of emission credits and improves the cost-effectiveness of the regulation. Although there does exist the risk that the TES could lead to high credit prices, this concern can be mitigated via an upper-bound on credit prices. The upper-bound acts as a safety-valve with the regulator issuing an unlimited number of credits at a fee equal to the upper-bound.

A firm i in sector j operating under an emission intensity constraint, $\overline{\gamma}$, and maximizing profit, would solve the problem

$$\underset{q_{i,j}}{max}\ \Pi_{i,j} = P_j q_{i,j} - C_{i,j}(q_{i,j}) \quad \text{such that } \frac{Z_{i,j}}{q_{i,j}} \leq \overline{\gamma} \tag{9}$$

Under a TES, if a firm produces at an average emission rate lower than the standard, it can sell (or bank for future) unused emission credits which equal the product of the difference between the target and actual emission intensity and the output (which, could be chosen to refer to either current output or output in a base period). Alternatively, when a firm's average emission rate exceed the standard, it can purchase emission credits from firms selling their excess credits for a given year and fulfill their obligations. Under such a system, the firm's problem becomes

$$\underset{q_{i,j}}{max}\ \Pi_{i,j} = P_j q_{i,j} - C_{i,j}(q_{i,j}) - \tau Z_{owed} \tag{10}$$

where, τ is the price of emission credits which is determined in equilibrium. The policymaker could set an upper limit on τ, which would ensure that the value of emission credits do not exceed a cap, beyond which firms could simply pay a tax on emissions abatement they 'owe'. The TES is in principle equivalent to a tax with rebates approach discussed above.

Different methods of calculating Z_{owed} will lead to different outcomes. In order to compare TES policies with different calculations for Z_{owed} to each other and to a Tax/TEP, let us assume that the emission intensity target under any TES is the same as that would result under a tax policy τ (or a TEP that would result in the same permit price) and denote this with the superscript *.

- Case 2a: $Z_{owed} = [\gamma_{i,j} - \overline{\gamma}^*]q_{i,j} = Z_{i,j} - \overline{\gamma}^* q_{i,j}$. In this case, the quantity of emission credits either generated or owed is dependent on current output, and so these are not determined in a lump-sum fashion. Comparing Equation 12 to Equation 6 for cost-effective policies, at a given price of emissions or emission credits, the TES in this case leads to more output since it lowers the marginal cost of increasing output.
- Case 2b: $Z_{owed} = [\gamma_{i,j} - \overline{\gamma}^*]q^0_{i,j} = [\frac{Z_{i,j}}{q_{i,j}} - \overline{\gamma}^*]q^0_{i,j}$. In this case emissions owed or credits generated is computed as the product of the difference between target and actual

emission intensity and the output in the base period.

- Case 2c: $\overline{\gamma} = \overline{\gamma}_i$ and $Z_{owed} = [\gamma_{i,j} - \overline{\gamma}_i]q_{i,j}$. This is a version of a TES or output-rebated emission tax in which each firm's performance is assessed relative to its own firm-specific target emission rate $\overline{\gamma}_i$. However, similar to Case $2a$, the emissions owed is based on a firm's current output $q_{i,j}$. A TES mandating a uniform percentage reduction in emission rate relative to each firm's own baseline rate is effectively such a type of TES, an instance of which is Alberta's SGER regulation.

The profit maximization condition for an individual firm under these different alternatives are as follows:

$$\text{Tax/TEP with lump-sum allowances - Cases 1a–1d:} \quad P_j - \tau^* \frac{dZ_{i,j}}{dq_{i,j}} = \frac{dC_{i,j}}{dq_{i,j}} \tag{11}$$

$$\text{TES Case 2a:} \quad P_j - \tau[\frac{dZ_{i,j}}{dq_{i,j}} - \overline{\gamma}^*] = \frac{dC_{i,j}}{dq_{i,j}} \tag{12}$$

$$\text{TES Case 2b:} \quad P_j - \tau[\frac{dZ_{i,j}}{dq_{i,j}} - \gamma_{i,j}]\frac{q^0_{i,j}}{q_{i,j}} = \frac{dC_{i,j}}{dq_{i,j}} \tag{13}$$

$$\text{TES Case 2c:} \quad P_j - \tau[\frac{dZ_{i,j}}{dq_{i,j}} - \overline{\gamma}_i] = \frac{dC_{i,j}}{dq_{i,j}} \tag{14}$$

We can see that relative to tax/TEP, each of the TES approaches lowers the marginal cost of emissions to a firm, resulting in higher output, lower prices, and higher emissions. It thus follows that to achieve any given level of emissions the emission intensity target needs to be set higher than that would result under a tax/TEP policy. The higher intensity target would imply a higher marginal abatement cost, lower output, higher prices and lower net social surplus.

Comparing design 2a and 2b of TES, the latter provides a larger (smaller) marginal output subsidy for firms whose average emission intensity is greater (lesses) than the industry average relative to the former. Design 2b imposes lowers the fee for non-compliance, when $q_{i,j} > q^0_{i,j}$. In other words, it provides less incentive to reduce output in order to reduce fee payments. Therefore, 2b will lead to higher output, lower prices and higher emissions relative to 2a.

Comparing design 2a and 2c of TES, the latter provides a larger (smaller) marginal output subsidy for firms when the firm-specific average performance target is higher than industry average performance target that would have resulted in the former design. 2c will lead to higher output, lower prices and higher emissions relative to 2a.

The additional inefficiency of designs 2b and 2c relative to 2a increases with the heterogeneity in emission performance across firms within an industry. A preference for either 2b or 2c over 2a could suggest a greater consideration on the part of policy makers to the cost of the regulation on the more pollution intensive firms.

3 Data and empirical analysis

We analyze data from 157 industrial facilities within the province of Alberta for the period 2004 to 2012. Each facility is classified as belonging to one among twelve industrial sectors – Chemicals, Coalmines, Fertilizer, Forestry (includes pulp and paper), Natural Gas extraction, Landfill, Mineral extraction and processing (includes facilities producing Cement, steel, magnesium oxide, limestone and metal recycling), *In situ* extraction of Oilsand, Oilsand mining[8], Pipelines, Electric power generation and Refining of Crude oil. Our dataset comprises of 89 regulated facilities and 65 unregulated facilities. It includes data on annual on-site emissions of six different GHGs, GHG emissions abated (as carbon dioxide equivalents) through the various compliance paths listed above, the emission intensity of each facility and the target emission intensity for each facility for each year beginning with 2007. We currently are beginning collection of additional covariates for each of these facilities such

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[8] In situ extraction and mining are two different ways of extracting bitumen, an intermediate substance that is then upgraded to crude oil for furthering refining. For more details refer `http://www.energy.alberta.ca/OurBusiness/oilsands.asp`

age, vintage, capacity, revenues etc.

3.1 Impact on emissions and output

We employ the following specification to estimate the average effect of the regulation on each sector.

$$Z_{i,t} = \alpha + \sum_{j=1}^{J} \beta_j D_i^{sger} * D_t^{t>2007} * D_i^j + \nu_i + \mu_t + \epsilon_{i,t} \tag{15}$$

where, i denotes a facility , j - denotes the sector to which the facility i belongs, t - denotes a year, Z denotes emissions, D_i^{sger} is a binary variable which denotes whether facility is under regulation,$D_t^{t>2007}$ is a binary variable which denotes whether the year of observation is post 2007, D_i^j is a binary variable which takes the value 1 if facility i belongs to sector j, ν_i denote facility -fixed effects, μ_t denote year-fixed effects, α is a constant term, and $\epsilon_{i,t}$ is an iid error.

Table 1: Sector-specific impact of the regulation

	(1) Actual emissions	(2) Net emissions	(3) Output
Dpolyrs*Dsger*Chemical	-210,435**	-238,330***	-561,842*
	(80,757)	(89,351)	(287,697)
Dpolyrs*Dsger*Coalmine	-32,750	-76,274	1059643***
	(69,198)	(72,938)	(38,027)
Dpolyrs*Dsger*Fertilizer	-477,162***	-536,713***	-1204624**
	(146,018)	(164,455)	(492,341)
Dpolyrs*Dsger*Gasplant	-116,954	-152,325**	-294,911**
	(70,938)	(71,565)	(145,169)
Dpolyrs*Dsger*Landfill	-288,855***	-293,016***	
	(78,972)	(79,114)	
Dpolyrs*Dsger*Mineral	-563,366***	-698,815***	-1656374***
	(194,764)	(141,031)	(625,293)
Dpolyrs*Dsger*OS-Insitu	195,681	151,808	952,174
	(190,276)	(196,622)	(631,028)
Dpolyrs*Dsger*OS-mining	-88,006	-330,890	-2682731
	(315,449)	(263,144)	(3978402)
Dpolyrs*Dsger*Pipeline	-222,857*	-324,197**	-3337370
	(117,324)	(158,216)	(2520670)
Dpolyrs*Dsger*Powerplant	-554,528**	-901,650**	-596,678**
	(259,028)	(366,193)	(284,487)
Dpolyrs*Dsger*Refining	-226,765**	-340,405***	-123,075

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Table 1 – continued from previous page

	(1) Actual emissions	(2) Net emissions	(3) Output
	(106,684)	(113,606)	(88,566)
Site FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
N	854	847	682
r2	.128	.212	.191

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The co-efficient β_j measures the average effect across all facilities in sector j in the years subsequent to 2007. Table 1 shows sector-wise effect of the regulation on three variables – actual emission at each facility, emissions at each facility net of abatement achieved using the three off-site compliance options, and finally, output or production at each regulated facility.

The regulation appears to have had a statistically significant negative impact on actual facility emissions on some sectors but no significant impact on other sectors. Interestingly, two sectors – coal mining and *in situ* oilsand extraction, show an increase in emissions. This can be attributed to the increase in output from these two sectors (See Column 3). For every sector, the net emissions from each facility is on average lower compared to actual on site emissions, which indicates the importance of the three compliance options related to off-site actions, namely, purchase of emission performance credits generated by other regulated facilities, offsets from unregulated facilities and penalty payments into the carbon fund. It is interesting to note that again coal mining and *in situ* oilsand extraction are the only two sector to have not experienced a significant negative effect on net emissions. In other words,

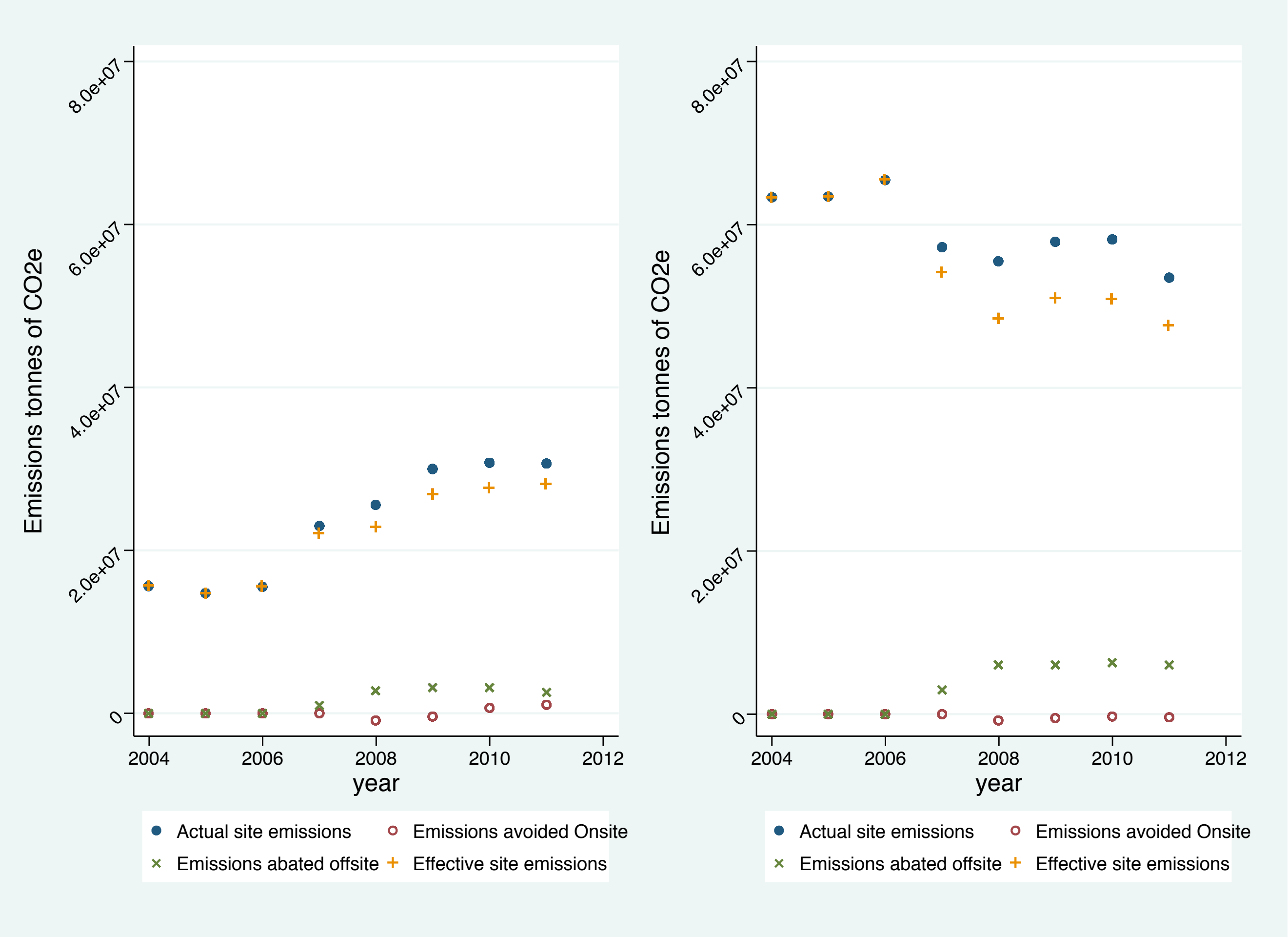

Figure 1: Annual total emissions from Extractive and Processing sectors

even emissions net of compliance continue to increase from this sector. Chemical, fertilizer, mineral and powerplant sectors experience a negative effect on output while only coal sector has experienced a significant positive effect on output [9].

The above results suggest distinct patterns of effects on different types of industries. Industries involved in the extraction of primary fuel sources such as coal, oil and natural gas and which are net producers of energy, appear to differ from industries that either use primary fuels to produce finished energy products such as oil products and electricity, namely, power generation and oil refining sectors or consume finished energy products to produce

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[9] needs further explanation

other products such as chemicals, fertilizer, and minerals. To test this, we therefore group different industries into three categories, namely, i) Extractive industries which comprises of Coal mining, Gas extraction, Oilsand - both in situ and mining; ii) Processing industries comprised of Chemicals, Fertilizers, Minerals, Power plants, Oil refining, Gas pipelines; and iii) Other industries comprised of Landfill and Forestry. Figure 1 depicts annual total emissions from the extractive and processing sectors, which shows different trends in actual and effective emissions. We then employed the same specification as Equation 15 with the difference that j denotes the industry group to which a site belongs. Table 2 confirms that the effect on extractive industries differs significantly from processing industries. It shows that the regulation has had no effect of facilities engaged in extraction of primary fuels while it has had negative effect on emissions from the energy consuming sectors. The impact on facilities in the forestry and landfill sectors is also negative since these sectors are net producers of emission performance credits.

Table 2: Impact of the regulation on different industry groups

	(1)	(2)
	Actual emissions	Net emissions
I_Dpolyrs_Dsger_Dextractive	-60,246	-109,549
	(78,606)	(78,999)
I_Dpolyrs_Dsger_Dprocessing	-414,451***	-598,224***
	(120,869)	(163,515)
I_Dpolyrs_Dsger_Dother	-291,872***	-297,719***
	(78,306)	(78,148)
Site FE	Yes	Yes
Time FE	Yes	Yes
N	854	847
r2	.0961	.159

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Shares of different compliance strategies in cumulative abatement from 2007-2012 by each sector. Note: There were no sites from the forestry sector with emissions exceeding 100,000 tonnes of CO_2e and hence these sites were exempt.

	Onsite improvements	EPC	Offsets	Fund payment
Chemical	-39%	16%	106%	17%
Coalmines	-14%	3%	32%	79%
Fertilizer	-64%	30%	13%	121%
Gasplant	-18%	6%	29%	83%
Landfill	77%	0%	0%	23%
Mineral	22%	0%	49%	29%
OS˙Insitu	27%	9%	7%	57%
OS˙mining	3%	40%	30%	27%
Pipeline	6%	0%	1%	93%
Powerplant	-3%	7%	57%	39%
Refining	-5%	19%	40%	46%

3.2 Analysis of compliance behavior

Table 3 shows the share of different compliance strategies in cumulative abatement from 2007 to 2012. A negative share, which is observed only for onsite improvements for certain sectors, implies that for those sectors the net effect of changes in emission intensity at various facilities was an effective increase in emissions. Only three sectors – Landfill, Minerals and in situ oilsands show significant reliance on onsite improvements. With the exception of Landfill sector, onsite improvements did not comprise the single largest contributor for any of the other sectors. The purchase of emission performance credits (EPC) comprises the single largest source of compliance for oilsand mining sector but is neither the largest nor the second-largest source of compliance for any of the other sectors. Onsite improvements and EPC taken together contribute less than 50% to compliance in every sector with the exception of the Landfill sector.

Figure 2 depicts the share of different compliance strategies in total annual abatement

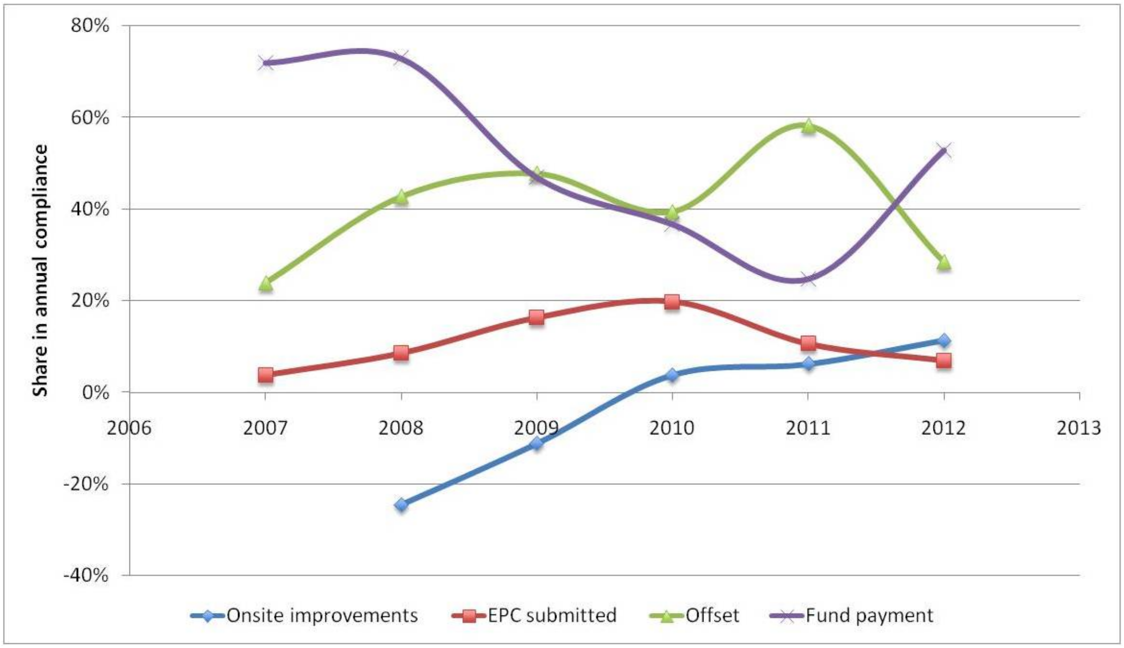

Figure 2: Shares of different compliance strategies in total annual abatement by all sectors

from all sectors in a given year. While there is a clear increasing trend in the share of onsite improvements with time although it comprises less than 20% of the emissions, Onsite improvements and EPC taken together contribute less than 25% to total abatement in any given year. The relatively small share of compliance via improvements in facility operations suggests that either there might be hidden costs to energy efficiency and thereby causing engineering-based cost estimates of energy efficiency to be biased downward.

3.3 Additional inefficiency of uniform site-level intensity reduction targets

The stipulation of uniform emission intensity reduction target (or equivalently a uniform percentage improvement in performance or emission intensity) for all facilities independent of their baseline emission intensity represents an additional source of inefficiency since it does not lead to equalization of marginal abatement cost even across facilities within a sector, let

Table 4: Intra-sector variation in the average emission intensity of a site across all the years, $\bar{\gamma}_{i,j}$. The table shows the number of sites within each sector, followed by mean, minimum and maximum of $\bar{\gamma}_{i,j}$ for each sector.

	# sites	mean	min	max
Chemical	6	0.7	0.12	1.7
Coalmines	4	0.0	0.02	0.1
Fertilizer	4	0.5	0.28	0.6
Gasplant	29	0.2	0.02	0.5
Landfill	1	11.7	11.7	11.7
Mineral	4	0.4	0.29	0.6
OS˙Insitu	14	0.5	0.12	1.1
OS˙mining	6	0.4	0.08	1.1
Pipeline	4	9.3	0.04	32.9
Powerplant	17	0.8	0.05	1.2
Refining	4	0.6	0.00	1.2

alone economy wide. Table 4 shows the intra-sector variation in the facility-average emission intensity $\bar{\gamma}_{i,j} = \frac{\sum_{t=1}^{T} \bar{\gamma}_{i,j,t}}{T}$, where i denotes facility and j denotes the sector to which the facility belongs. It shows that for within each sector there exists considerable variation in the average emission intensity.

4 Discussion

Concerns about revenue loss to private sector under efficient or cost-effective policies can be addressed in different ways without sacrificing the incentives for long-run efficiency or cost-effectiveness via rebate on emission tax (or grand-fathering tradable emission permits) and making the rebates a property-right (just as emission permits tend to be). These adjustments, however, do not compensate for foregone future profits due to slower growth in output under efficient or cost-effective policies, rendering these schemes still hard to implement. This problem is particularly pronounced for climate change policies undertaken at state or even national level in the absence of globally uniform regulations on GHG emissions.

Polluters who as group tend to have considerable political power therefore tend to demand greater concessions from policy makers. Tradable emission performance standards (TES) are an increasingly popular alternative whose political feasibility is gained by sacrificing cost-effectiveness. To achieve a given level of emissions via TES would require mandating more stringent emission intensity target than would result under a tax/TEP scheme. This implies a higher marginal abatement cost, lower output, higher prices and lower net social surplus.

Expanding the scope of the TES scheme to include as many polluters spread across multiple sectors would help reduce the cost of TES just as it would under a tax/TEP approach. However, an added challenge in designing TES in a multi-sectoral context is the select of a performance target for each sector as an uniform intensity target for all the different sectors is impractical. The variation in average emission intensity of output for the 11 sectors in Alberta is a case in point. Alberta's SGER overcomes this limitation assigning a uniform percentage emission intensity reduction target for all sectors. This, however, increases the cost of the regulation for marginal abatement costs are not equalized across sectors. The SGER takes another step away from cost-effectiveness by assigning the same uniform percentage emission intensity reduction target to all firms within a sector. This means that each firm faces a different emission intensity target, akin to what results under to command and control style regulations that mandate source-specific emission limits or technology standards.

While the inefficiency on source-specific emission intensity standards is immediately apparent, one useful insight to emerge from the empirical investigation concerns the reliability of engineering estimates of the cost-effectiveness of carbon abatements through engineering improvements to industrial operations. The relative small share of onsite improvements by facilities in total compliance does not accord well with engineering estimates of abatement cost of GHG emissions from industrial sources. On the contrary, for six out of the twelve sectors onsite improvements contribute negatively, i.e., for these sectors the net effect of the changes emission intensity across the different years and different facilities was an increase in emissions. Province-wide, the combined contribution of engineering improvements within regulated facilities, measured by sum of emission avoided onsite and compliance achieved by purchase of emission performance credits, contributed no more than 25 percent in any given year. It is however worth noting again that the share of onsite improvements in total compliance is increasing each year, but the rate of increase seems to have slowed.

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