Offsets for Carbon Sequestration in Agricultural Soil and Tradable Emission Permits for Large Final Emitters

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Executive Summary

As part of its plan for honouring Canada's Kyoto Commitment, the Government of Canada will require large final emitters (electricity generators, the oil and gas sector and mining and manufacturing) to meet **emissions intensity targets.** Companies can meet their intensity targets by internal reductions in emissions intensity, by purchasing credits from other companies that have done better than their emission intensity targets, or by purchasing **domestic offset credits such as those that may be created by agricultural and forestry sinks.** The Government also has promised a **price assurance mechanism** to ensure that companies will be able to meet their regulatory obligations at a cost of no more than $15/tonne.

Emissions intensity targets, offset credits, and the price assurance mechanism, are all intended to **assist large final emitters to achieve reductions in greenhouse gas emissions in a manner that that supports the continued competitiveness of industry.** This is a legitimate objective, but the combination of policies that are proposed to achieve it will have other negative consequences.

An emission intensity target creates a system which effectively taxes emissions and subsidizes output. This leads to reduced emissions intensity, but output and emissions may increase. In such a system providing **cheap offset credits, or a price assurance mechanism, to assist large final emitters in meeting their targets creates further incentives to increase output and emissions.** Both of these reduce the marginal abatement cost and the cost of producing output. The latter allows output and emissions to increase relative to the case with intensity targets alone.

A better alternative would be to allow offsets credits and/or a price assurance mechanism in combination with an absolute cap on emissions. This would provide reduced marginal abatement costs without increased emissions.

1 Background

Many countries are facing difficulty meeting their Kyoto commitments. During the period 1990 to 2003 greenhouse gas emissions in highly industrialized counties increased by about 9.2%. Canada is among those countries running into difficulty implementing its commitments. In 2003 the country had increased its emissions by 24.2 % from the base 1990 level, far from its 2012 target of a 6 % reduction. The U.S. had increased its emissions by 13.3% compared to its original target of a 7% reduction.[1] These difficulties have lead to the U.S. rejecting Kyoto, saying the treaty's emission-reduction targets would harm the American economy and workers, and more generally a desire for "practical commitments industrialized countries can meet without damaging their economies".[2] Hence the interest in carbon intensity targets. In 2002, the United States announced plans to reduce its carbon intensity 18 percent by 2012.

In Canada, large final emitters (electricity generators, the oil and gas sector and mining and manufacturing) will be rquired to meet intensity targets. The large final emitter (*LFE*) system is intended to achieve reductions in greenhouse gas emissions in a manner that supports the continued competitiveness of industry. The proposed *LFE* regulations would prescribe specific emission intensity targets for industrial activities in each *LFE* sector. Emission intensity targets define an allowed amount of greenhouse gas emissions (in carbon dioxide equivalency) per unit of output, where output is defined according to sector. The guidelines for intensity targets are specified in the Notice of Intent to Regulate Greenhouse Gas Emissions by Large Final Emitters.[3] The idea behind intensity targets for *LFE's* is that an output-based, or emissions intensity, approach to target setting does not penalize growth in output or reward a decline in output.

***LFE* companies can meet their intensity targets by internal reductions in emissions intensity, by purchasing credits from other *LFE* companies that have done better than their emission intensity targets, or by purchasing domestic offset credits.[4]** The *Climate Change Plan for Canada* proposes to allow the creation of offset credits for agricultural and forestry sinks. [5]The Government also has promised a "price assurance mechanism" to ensure that *LFE* companies will be able to meet their regulatory obligations at a cost of no more than $15/tonne for the period 2008-2012. Finally, the Government has agreed to set up a Climate Fund which will also purchase emission reductions (e.g. renewable energy projects) and removals (agriculture and forestry sinks).

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[1] United Nations Framework Convention on Climate Change, *National Greenhouse Gas Inventory Data for the Period 1990-2003 and Status of Reporting,* Nov. 2005, http://unfccc.int/resource/docs/2005/sbi/eng/17.pdf, accessed February 17, 2006.

[2] Pew Centre on Global Climate Change. http://www.pewclimate.org/policy_center/analyses/response_bushpolicy.cfm, accessed February 16, 2006.

[3] July 16, 2005, *Canada Gazette Part I*, Vol. 139 No. 29 (http://www.ec.gc.ca/CEPARegistry/notices/NoticeText.cfm?intNotice=318&intDocument=2156.

[4] They also have the option of using of non-tradable Technology Investment Units gained by investing in the proposed Greenhouse Gas Technology Investment Fund or other qualifying investments; or International Kyoto units, including credits from Clean Development Mechanism (CDM) and Joint Implementation (JI) projects and "greened" Assigned Amount Units (AAUs). However, the recent change in government may remove some of these options. See "Canadian Companies won't get to buy Credits under Kyoto: Ambrose," National Post, Saturday, Feb. 18, 2006

[5] http://www.climatechange.gc.ca/english/ccplan.asp, accessed February 19, 2006.

The purpose of this document is to investigate the benefits and costs of intensity targets relative to absolute targets, when used alone or in combination with a per tonne price cap and/or sequestration offsets. The next section (2) investigates the definition of intensity and the arguments in favour of intensity targets. Section 3 develops a theoretical model which shows both the benefits and costs associated with intensity targets when there is uncertainty about marginal abatement costs. Section 4 adds the option of sequestration to the model developed in section 3. Sections 5 and 6 present simulation results based on the models in sections 3 and 4, and section 7 draws conclusions and makes recommendations for future research.

2 Why Intensity Targets?

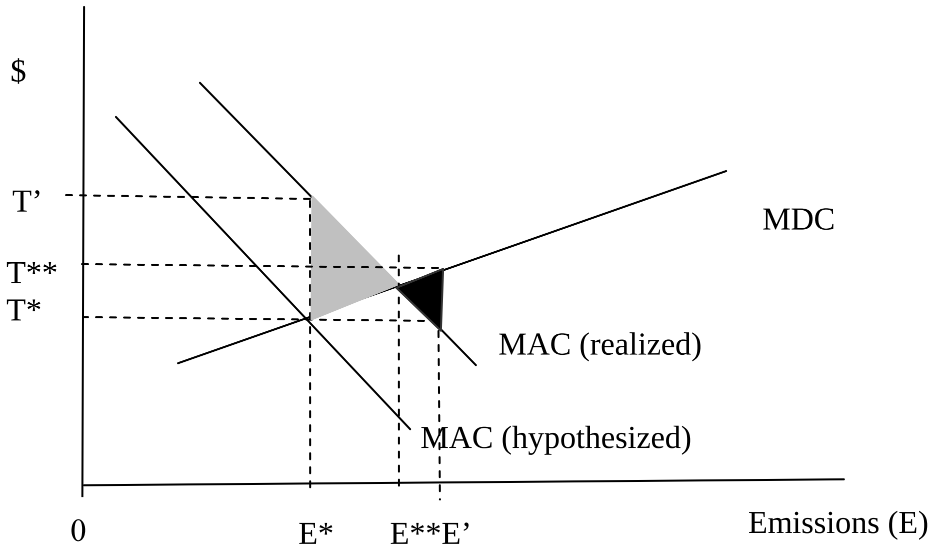
Abatement Cost Uncertainty and Intensity Targets. Intensity targets are viewed as a desirable alternative to the absolute caps that are typically part of emissions permit trading because they restrict emissions intensity and not output, and because they take some of the uncertainty out of the cost of compliance for emitters.

With certainty with respect to the damages associated with emissions and the cost of abating those emissions, either an emissions tax or an emissions cap can be set to produce the optimal level of emissions (the level that minimizes the sum of abatement plus damage costs or at which the marginal damage cost equals the marginal abatement cost). When there is uncertainty with respect to abatement costs, an expect or hypothesized marginal abatement cost must be used in setting the emissions tax or cap. The argument for intensity targets is based on a literature in environmental economics which shows, that with uncertainty about marginal abatement costs, the choice of an optimal pollution control instrument depends on the relative steepness of the marginal damage and marginal expected cost functions.

Consider Figure 1 below which shows a relatively steep marginal abatement cost *(MAC)* curve and a relatively flat marginal damage cost *(MDC)* curve. The marginal abatement cost is uncertain, while the marginal damage cost is certain. This means that the levels of regulatory instruments (emissions tax versus a tradable emission permits *(TEP's)* system with an absolute emissions cap) must be based on *MDC* and hypothesized *MAC*. This would result in tax *T** or an emissions cap of *E**. However, realized *MAC* turns out to be higher than hypothesized. If the tax *T** has been set, polluters will choose to emit *E'* worth of emissions, greater than the expected amount E*, and greater than the optimal amount given the realized *MAC (E**)*. At *E' MDC* exceeds the realized *MAC* by *T**-T*.* The total loss associated with ending up at *E'* rather than *E** is the small black triangle in Figure 1. If instead the emissions cap *E** had been set emissions would not change because realized MAC exceeds hypothesized MAC. However, the marginal abatement cost to achieve the cap is *T'* rather than *T*.* The loss associated with ending up at *E** rather than *E*** is the extra abatement cost net of damages avoided. The loss is measured by the larger grey triangle in Figure 1. Comparing the large grey triangle with the small black triangle shows that the emissions cap imposes a greater loss than the emissions tax.

In general uncertain marginal abatement costs result in losses that differ across price (tax) and quantity (emissions cap) regulations, depending on the relative slopes of the *MAC* and *MDC* functions. When the *MAC* is steeper than the *MDC*, cost uncertainty is more important than emissions level uncertainty, and the loss is minimized by choosing an emissions tax rather than a cap.

Figure 1: Losses Associated with Uncertain Marginal Abatement Costs



There can also be uncertainty with respect to the *MDC* function. However, uncertainly in the MDC does not affect the choice of regulatory instrument, only uncertainty in the *MAC*. [6]

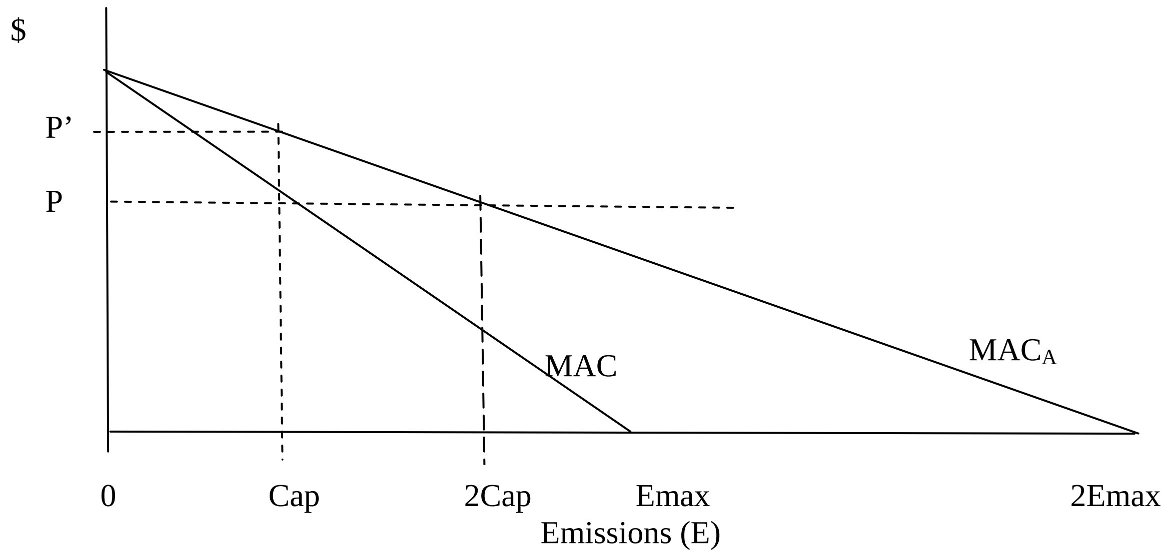
What do we know about uncertainty and relative slopes of *MAC* and *MDC* curves for $C0_2$ emissions? There is a significant distinction between the damage from $C0_2$ and other conventional pollutants like SO_2 or NO_x. As suggested by UNFCCC, the goal for climate change policies should be focused on long-term concentration levels related to accumulated emissions over many decades, The level of emissions in a given year is less important than the overall stock of emissions in the atmosphere. This implies that the MDC curve for $C0_2$ emissions in a given year is rather flat (Pizer 2005).

On the other hand, marginal abatement costs for $C0_2$ vary significantly between countries, industries and individual firms, which suggest that inherent uncertainty around marginal costs is high and the marginal cost curve is rather steep. A major source of uncertainty is that related to growth in output. A strong correlation exists between output and emissions, and uncertainty about output translates into uncertainty about the marginal cost of emissions abatement.

Figure 2 shows one firm's marginal abatement cost with an unconstrained emissions level of *Emax* at the plant that it operates. The firm faces a emissions cap at which its marginal abatement cost is *P*. Now assume an increased demand for output. The firm opens another plant with the same marginal abatement cost function as its first plant. The second plant allows it to double its output, and its unconstrained emissions will also double to 2*Emax.* Its aggregate marginal abatement cost over the two plants is $MAC_{A,}$ If the firm still faces the same cap on its emissions, it's marginal abatement cost will rise above *P* to *P*'. However, if its cap is doubled to reflect the doubling of its output the marginal abatement cost remains at *P*.

[6] See Appendix A for the analysis of this case.

Figure 2: MAC Increasing with Output



It has been shown that there is a strong correlation between emissions and output (Pizer, 2005). With uncertainty surrounding the marginal abatement costs associated with $C0_2$ emission reductions, stringent quantity controls on emissions translate into stringent restrictions on output. This raises strong concerns about the capacity of quantity controls like absolute emissions caps to limit economic growth.

However, regardless of the potential loss associated with an absolute cap in the face of uncertain marginal abatement costs, the *TEPs* system has some advantages over an emissions tax for policy makers. For example:

- The government can give out most of the emission permits gratis rather than making emitters pay for them, and a free distribution approach to the initial allocation of permits has been necessary ingredient in building the political support necessary to implement the policy.
- The emission tax is difficult to accommodate on global level as an international tax is politically infeasible.

Therefore the question is not emission charges versus *TEPs* but how one can work the advantages of price instrument into a quantity instrument to avoid the losses associated with larger than expected marginal abatement costs.

Several design features have been proposed to make *TEPs* more flexible. Three of these include: i) using emission intensity limits rather than absolute emission limits, ii) fixing a maximal price for permits as safety valve, and iii) providing low cost options to purchase offsets such as those produced by sequestration of carbon in forests or agricultural soils. Canada proposes to use all three.

3. Modeling Tradable Permits with an Absolute Cap versus an Intensity Limit

Currently there are two widely discussed forms of emission limits possible for use with tradable emission permits (TEPs): absolute limits and intensity limits. Absolute limits target emission reductions to some pre-specified absolute quantity and intensity-based targets restrict emissions to some, pre-specified rate relative to output (Ellerman and Wing. 2003).

In the case of **absolute limits** $C0_2$ reductions are usually expressed as a maximum level of allowed emissions (tonnes of $C0_2$), or the difference between an allowable or target level of emissions and an existing or baseline level. An absolute limit usually applies to a particular time period. But, a set of absolute limits can be used to define an aggregate emissions path through time. As is the case with countries' commitments under the Kyoto Protocol, limits can be expressed as percentage reductions from a baseline to be achieved by a given date(s).

Intensity limits are expressed as maximum allowed emissions intensity, or as the difference between a target emission intensity and an existing level. Intensity limits are to be reached in a particular time period. Alternatively, intensity limits are expressed as a targeted rate of decline in intensity (%) and can be applied indefinitely. [7]

For the purpose of this work **emissions intensity** is specified as an amount of emissions per unit of output. This measure provides an indication of how efficiently, in greenhouse gas emission terms, a firm, industry sector or economy is able to operate. Generally, in some time period t, emission intensity is calculated as:

$$\mu_t = \frac{E_t}{Q_t},$$

where, μ_τ is emissions intensity, E_t is quantity of emissions and Q_t is level of output.

To compare absolute limits and intensity limits*, consider a representative *LFE* who is trying to maximize profits while facing one of these two limits.* The modeling approach that is used to analyze intensity limits and compare them with absolute limits follows closely that of Fisher (2003).

Consider a perfectly competitive firm which is a representative emitter among a set of emitters regulated by an absolute cap. The representative firm maximizes the following profit function:

$$\pi_1 = \left(P_1 - c_1(\mu_1) - t_1\mu_1\right)Q_1 + t_1 A \qquad (1)$$

where: $\pi_1$is the firm's profit,

- P_1 is the equilibrium output price,
- μ_1 is the emissions intensity per unit of output.
- $c_1(\mu_1)>0$ is the cost of reducing emissions intensity,
- $c'_1\mu_1)\leq 0$ is the marginal cost (negative) of increasing emissions intensity,
- $c''_1(\mu_1)>0$ is the change in the marginal cost (becoming less negative) with increasing intensity,
- t_1 is the market price of an emission permit,
- Q_1 is quantity of output produced by the firm, and
- A is the initial allocation of permits to the firm.

The firm chooses an emissions intensity (μ^*_1) and a level of output *(Q^*_1)* to maximize its profits. The profit maximizing emissions intensity, μ^*_1, is the one at which the marginal cost saving from a small increase in intensity is equal to the price of the permit required to accommodate it.

[7] See Appendix B for a discussion of various intensity measures that appear in the literature.

$$-c_1'(\mu_1^*) = t_1 \qquad (2)$$

The profit maximizing output, Q^*_1, is the one at which the marginal cost of producing another unit is equal to the price it will bring.

$$P_1^* = c_1(\mu_1^*) + t_1\mu_1^* \qquad (3)$$

The individual firm is a price taker in both the output and permits markets, but the equilibrium prices are determined by aggregate demand and supply. In the output market the aggregate demand is exogenous and represented by $Q^*_1 = Q_1\ (P^*_1)$, where P^*_1 is determined by (3). In the permit market the permit supply is exogenous because it is regulated, so $\mu^*_1\ Q^*_1 = A$. This and (2) determine the permit price.

An equivalent solution would have been obtained had the regulator set an emission tax equal to the equilibrium permit price. An emission tax set at a lower (higher) level would have resulted in a higher (lower) choice of emissions intensity, a lower (higher) marginal cost of output, and a higher (lower) choice of output.

Now consider a representative firm facing an intensity target, requiring that emissions intensity be no greater than μ.

Its profit function is:

$$\pi_2 = \left(P_2 - c_2(\mu_2) - t_2(\mu_2 - \mu)\right)Q_2 \qquad (4)$$

It also chooses its emissions intensity (μ^*_2) and its output *(Q^*_2)* to maximize its profit, satisfying the marginal conditions in (5) and (6).

$$-c_2'(\mu_2^*) = t_2^* \qquad (5)$$
$$P_2^* = c_2(\mu_2^*) + t_2^*(\mu_2^* - \mu) \qquad (6)$$

Again, market equilibrium in the output market is determined by $Q^*_2 = Q_2\ (P^*_2)$, where P^*_2 is determined by (6). However, with an intensity target, $\mu^*_2 = \mu$. This means t^*_2 is determined by $-c'_2(\mu) = t^*_2$, $P^*_2 = c_2(\mu)$ and $Q^*_2 = Q_2\ (c_2(\mu))$.

Relative to the absolute cap, the intensity target provides a subsidy to output resulting in greater output and emissions under the intensity target than under the absolute target. With the intensity target, the marginal cost of output is less because the second term on the right hand side of (6) is zero. This means that the price of output is less and output is greater than under an absolute cap. If the emissions intensity rate was set such that $t^*_1 = t^*_2$, then $\mu = \mu^*_2 = \mu^*_1$, but Q^*_2 would be greater than Q^*_1 and there would be greater total emissions under the intensity target system than under the absolute cap. Conversely if $t^*_1 < t^*_2$, $\mu = \mu^*_2 < \mu^*_1$ is required if total emissions are to be the same under the two systems.

As in the case of the absolute cap, it is possible to use an emissions tax to achieve the same result as the target. However, the emissions tax is accompanied by a subsidy to output. In (6) the tax and the subsidy exactly cancel and output is affected by the tax only through its influence on the cost of output, $c_2(\mu^*_2)$. A lower (higher) tax would mean higher (lower) emissions intensity, a lower (higher) cost of output, and a higher (lower) output level. But, the influence of a lower (higher) emissions tax on output is damped by the output subsidy.

4. Modeling Tradable Permits with Sequestration Offsets

Now consider allowing sequestration offsets,produced by perfectly competitive agricultural or forestry firms, to be sold into a *TEP's* system. Let *m* be the number of tonnes of emissions permanently
sequestered by a representative firm, *k(m)* be the cost of that sequestration, and *k'(m)* be the marginal cost with *k'(m)*>0 and non-decreasing in *m*.

First assume the sequestration firm sells offsets into a *TEP's* system with an absolute cap. The sequestration firm is a price taker in the permit market and market price for the equivalent of a tonne of emissions sequestered is t_S. The sequestration firm's profit function for offset production is:

$$\pi_S = t_S m_1 - k(m_1) \qquad (7)$$

The profit maximizing condition for this firm is:

$$t_S = k'(m_1) \qquad (8)$$

With an absolute cap in the TEP's **sector, the *LFE* firm now maximizes profit but takes into account possibility of purchasing sequestration offsets rather than abating.** Its profit function is now given by (9). The only difference between (9) and (1) is that the term $t_1 A$ has been replaced by $t_1(A+m_1)$.

$$\pi_1 = \left(P_1 - c_1(\mu_1) - t_1\mu_1\right)Q_1 - t_S m_1 + t_1\left(A + m_1\right) \qquad (9)$$

Since sequestration offsets are sold in the permits market, both t_1 and t_s will equal the market equilibrium price, t^o_I. The first order condition for m_1 is $t^o_I = t_1 = t_S$ Using this condition, the first order conditions for Q^o_1 and μ^o_1 are:

$$-c_1'(\mu_1^o) = t_1^o \qquad (10)$$
$$P_1^o = c_1(\mu_1^o) + t_1^o\mu_1^o \qquad (11)$$

Since offsets will only be purchased if they are cheaper than abatement, gross emissions will increase, but the absolute cap will prevent emissions net of removals from increasing. If the use of sequestration can increase the firm's profits it will choose to use sequestration offsets. It will choose the level of offset use versus emissions abatement by equating marginal abatement costs with marginal sequestration costs. The emissions tax, t^o_1, will be less than it was with no offsets ($t^o_1 < t^*_1$). This results in $\mu^o_1 > \mu^*_1$, $c_1(\mu^o_1) < c_1(\mu^*_1)$, $P^o_1 < P^*_1$ and $Q^o_1 > Q^*_1$. Now $\mu^o_1 Q^o_1 = A + m_1$ so although emissions increase, emissions net of sequestration removals do not.

Now assume the sequestration firm sells to an *LFE* firm facing an intensity target. With an intensity target, the sequestration firm sells to a representative *LFE* firm where the offset price is t_S. This changes the right-hand side terms in (7) to $t_S m_2 - k(m_2)$ and the first order condition in (8) becomes:

$$t_S = k'(m_2) \qquad (12)$$

The representative firm in the intensity limited sector now maximizes its profits with the option of buying offsets. The profit function is (13).

$$\pi_2 = \left(P_2 - c_2(\mu_2) - t_2(\mu_2 - \mu)\right)Q_2 - t_s m_2 + t_2 m_2 \quad (13)$$

The first order condition for m_2 is $t^o_2 = t_2 = t_S$ The marginal conditions for profit maximizing levels μ^o_2 and Q^o_2 are:

$$-c_2'(\mu_2^o) = t_2^o \quad (14)$$

$$P_2^o = c_2(\mu_2^o) + t_2^o(\mu_2^o - \mu) \quad (15)$$

Emissions will increase as will emissions net of sequestration removals. Again it will be true that offsets will only be used if they are cheaper than abatement, so t^o_2 will be less than it was with no offsets. *Now* $\mu^o_2 = \mu + (m^o_2/Q^o_2) > u^*_2$. P^o_2 will be smaller than P^*_2, *and* Q^o_2 will be greater than Q^*_2. Emissions will increase as will emissions net of sequestration removals.

Now compare the absolute target *TEPs* (with offsets) to the intensity based *TEPs* (with offsets). If $t^o_1 = t^o_2$, the same quantity of offsets will be purchased, $m_1 = m_2$, and the emissions intensity level will be the same, $\mu^o_1 = \mu^o_2$, but $P^o_1 > P^o_2$, $Q^o_1 < Q^o_2$ and $A < \mu^o_1 Q^o_1 - m_1 < \mu^o_2 Q^o_2 - m_2$. To keep emissions from increasing above $A + m_2$ it will be necessary to reduce the intensity limit such that $\mu = \mu^o_2 < \mu^o_1$. This will raise P^o_2 and lower Q^o_2. In addition, it will result in $t^o_2 > t^o_1$ *and* $m_2 > m_1$. More sequestration offsets will be purchased.

An increase in the demand for output means that the quantity of output demanded increases at a given price. This increases the demand for sequestration offsets to allow emissions. At a given intensity there will be a greater amount of output and the tendency of intensity based *TEP's* to encourage increased emissions will be amplified.

For the same intensity level, an intensity limited *TEP's* system will generate more emissions than and absolute cap *TEPs* system.

5. Simulations without Sequestration

To see these results more clearly, a simulation has been created. The specific functional forms and parameters are given below. The same functions are used for both the *i=1* (absolute limit) and *i=2* (intensity limit) cases.

> $P_i\ (Q)=B-2Q_i$ is the exogenous demand for output and B varies from 18 to 26,
> $c_i\ (\mu)=(4-\mu_i)^2$, where 4 is a maximum feasible intensity level,
> $c_i'\mu_i)= -2\ (4-\mu_i)$is the marginal cost (negative) of increasing emissions intensity,
> $c'_i(\mu_i)$=2>0 is the change in the marginal cost (becoming less negative) with increasing intensity,
> t_i is the market price of an emission permit,
> Q_i is quantity of output produced by the firm,
> A=14 is the cap on the allowed emissions,
> μ=2.82 is the intensity cap,
> $k(m)= m$ is the cost of sequestration, and
> k_m=1 is the marginal cost of sequestration.

A marginal damage function is introduced to make it possible to show welfare losses similar to those in Figure 1. The marginal damage function is assumed to be discontinuous at 14 units of emissions. Marginal damages are set at zero for emission levels up to 14. At 14 units of emissions the marginal damage jumps to 2.36 and from then on increases by 0.025 per unit of emissions.

Table 1 shows the results for the case without the option of purchasing sequestration offsets. The level of output demand is initially set at B=18 and then increased to B=26. The absolute cap is varied from 12 to 42 to reveal the marginal damages *(MD)* at each level of emissions, and the emissions intensity and marginal abatement costs *(MAC's)* for each level of emissions at each of the two demand levels. The intensity standard is set to equal the chosen intensity under the absolute cap at B=18 (μ=2.82). As the theory indicates, for the same intensity level the firm under intensity limit will produce more output and more emissions than the firm facing the absolute cap. This is because the marginal cost of a unit of output is $c_1(\mu^*_1)+t_1\mu^*_1$ under the absolute cap, but only $c_2(\mu^*_2)$ under the intensity cap.

Absolute cap. Figure 3 shows the *MAC's* for B=18 and B=26 and the marginal damages. When B=18, *MAC=MD*=2.36 at the emissions cap of 14. When B is increased to 26, the MAC shifts to the right. Now *MAC=MD* at an emissions level of 23. If the absolute cap remains at 14, there is a welfare loss equal to the grey triangle. Emitters are being forced to incur marginal abatement costs in excess of the marginal damages avoided by their emission reductions.

When output demand and marginal abatement cost increase under an absolute cap, there is a large welfare loss because marginal abatement costs will greatly exceed marginal damages at the cap.

Emissions tax. If, instead of a cap, an emissions tax 2.36 per unit of emissions had been imposed, emissions would have increased from 14 to 26 when B increased from 18 to 26. Moving from an emissions level of 14 to an emissions level of 26 creates both a welfare gain (the grey triangle in Figure 3) and a small welfare loss (the black triangle in Figure 3). The small welfare loss is the black triangle to the left the emissions level of 26. This is considerably smaller than the grey triangle. Hence, there the emissions tax has an advantage over the absolute cap given a steeper *MAC* and uncertainty about the level of the *MAC*.

When output demand and marginal abatement cost increase under an emissions tax there is an increase in output and emissions, and a small welfare loss because marginal damages will exceed marginal damages at the emissions level where the tax equals the new marginal abatement cost.

Intensity limit. Unlike the emissions tax, the intensity limit is not clearly preferable to the absolute cap. Under the intensity regime, an intensity cap was set at μ=2.82. At *B*=18 emissions of 23.42 were produced. When μ=2.82 the *MAC* of meeting that limit is 2.36. However, emissions could be abated to a level of 23.42 more cheaply with an absolute cap set at that level. With an absolute cap set at 23.42, *MAC*=1.17. Hence, with *B*=18 and intensity cap of μ=2.82, there is a welfare loss, shown by the grey triangle in Figure 4.

When *B* is increased to 26, the same intensity level is chosen and the *MAC* associated with meeting μ=2.82 *remains* at 2.36. However, now output increases and emissions increases to 34.7. Moving from an emissions level of 14 to an emissions level of 34.7 creates both a welfare gain (the grey triangle in Figure 5) and a welfare loss similar to that shown in Figure 4. The welfare loss occurs because *MD* >*MAC* at the chosen emissions level of 34.7. This loss is shown in Figure 5 as the large black triangle.[8] It is larger than the loss associated with the emissions tax/

For the same emissions intensity level, the firm under Intensity limit will produce more output and more emissions than the firm facing the absolute cap or the emissions tax. This results in a welfare loss larger than that associated with the emissions tax, because marginal damages will exceed marginal abatement costs by a larger amount at the chosen level of emissions.

[8] Regulatory instruments like emissions taxes and *TEPs* are also intended to create incentives for the development of new abatement technologies to reduce marginal abatement costs. Intensity limits put a strong focus on reducing emissions intensity, but the built in subsidy to output lowers output prices and reduces the incentive for innovation (Fischer, 2000).

6. Simulations with Sequestration

Table 2 shows simulation results with the option for sequestration introduced. The margin cost of sequestration is constant at $k'(m)=1$. For interior solutions (when some sequestration and some intensity level below the maximum are chosen), this is also the marginal abatement cost.

Absolute cap. With a demand level of *B*=18 and an absolute cap at an emissions level of 14, the cap is met with a *MAC*=1. Emissions will be reduced from 36 to 25 through abatement and there will be roughly 11 units of sequestration. When *B* increases to 26, the range of emissions levels over which *MAC*=1 expands, and sequestration offsets will be used to cover a larger portion of the required emissions reduction. The availability of the cheap sequestration option, because it allows emitter to avoid high abatement costs, eliminates the welfare loss that would otherwise have been associated with the increase in demand for output.

With an absolute cap, a cheap sequestration option allows emitters to avoid high abatement costs and eliminates the welfare loss that would otherwise have been associated with the increase in demand for output.

Intensity limit. If an intensity limit is used with sequestration option the result if different. The intensity cap remains at the non-sequestration level of $\mu=2.82$. However, $k'(m)=1$ caps the *MAC* at 1. With sequestration, the intensity level chosen will be above the cap *(3.5>2.,82),* and the emissions level will increase relative to the no-sequestration option as a result of the lower marginal cost of output. Sequestration will offset some but not all of the increase in emissions. Emissions net of sequestration are $Q^o_2\mu^o_2 - Q^o_2(\mu^o_2-\mu) = Q^o_2\mu$. Without the sequestration option emissions would have been $Q^o_2\mu$. Since $Q^o_2>Q^*_2$ net emissions must be greater when cheap sequestration is available. In Figure *6* the availability of cheap sequestration $(k'(m)=1<2.36)$ results in gross and net emissions of 28.89 and 24.08 with a demand level of *B=18.* When the demand level increases to *B=26* the gross emissions are *43.9* and net emissions are *35.4.* The latter compares to 34.7 for the no-sequestration case.

The high level of net emissions for the sequestration case also creates a welfare loss. Marginal damages exceed the marginal cost of sequestration for all emission levels in excess of *14.* When *B*=18 the welfare loss is the large grey trapezoid to the left of the emissions level of 24.08 in Figure 6. When *B=26* it is the whole grey trapezoid.

With an intensity limit, the introduction of a cheap sequestration option results in further increases in emissions and creates a further welfare loss.

The Canadian proposal contains both a sequestration option and a price cap *($15* per tonne) on emissions. The latter ensures that emitters will be able to buy emission permits from the regulator at the specified price and will never have to incur marginal abatement costs above that price cap. If the regulator is able to provide real emission reduction at the price cap, then it acts like a constant sequestration offset price. What becomes important is whether the price cap is above or below the sequestration offset price. If the sequestration offset price is lower, offsets will be purchased instead of the price capped permits. If the price cap is lower, there will be no demand for offsets.

Both the price cap and the sequestration option could be included in the theoretical models and the simulation. For example, suppose that the marginal cost of sequestration was $k'(m)=m$ and the price cap was $t_C=1$. The price cap would determine the price of sequestration offsets and the quantity used. The price would be $t^o_1=1$ in the absolute system and $t^o_2=1$ in the intensity based system. One unit of sequestration would be purchased in either system. In the absolute system the net emissions cap of *14* would always be met. With the demand level of *B*=18, 9.96 price capped permits would be purchased and one sequestration offset. With a demand level of *B*=26, 23.96 price capped permits would be purchased and one offset (Table *2).* For the intensity based system one unit of offsets would be purchased regardless of the demand level, and 4.81 or 7.52 units of price capped permits, depending on the demand level (Table *2).* [9]

The Canadian proposal contains both a sequestration option and a price cap ($15 per tonne) on emissions. The price cap puts a limit on how much *LFE* firms will pay for sequestration offsets and on how many offsets they will buy. Offsets will be purchased only to the extent they are cheaper, and the demand for them is likely to be severely limited by the price cap.

[9] Manley *et.al.* perform a meta-analysis of the cost of carbon sequestration in agricultural soils and find that there are areas where low cost options can be generated (the U.S. South) and other (northern Great Plains) where offsets will be too expensive to be used extensively.

7. Conclusion

Intensity targets are intended to prevent the increase in marginal abatement cost that stems from an increase in demand for an emitter's output. However, if an intensity target is set low enough to avoid the increase in marginal abatement cost there will be increases both output and emissions. These increases will be greater than those resulting from an emissions tax to retain the same level of marginal abatement cost, and will result in greater welfare losses.

Under an absolute cap, cheap and effective sequestration offsets can be used to avoid the welfare losses that would otherwise result when an emitter's realized marginal abatement cost exceeds it the expected level used in setting the cap. Under an intensity limit, cheap offsets cause output and net emissions to increase above their no-sequestration levels and cause welfare losses. Emissions intensity limits do provide a way to limit the losses associated with realized marginal abatement exceeding expected marginal abatement costs. However, the flexibility that is provided by the intensity cap also has a downside. As demand for output grows, that flexibility results in emissions growing. Unless the intensity target is adjusted downward as output grows emissions will exceed any given absolute cap (A). Kolstad (2005) has pointed out that the growth rate for emissions is the sum of the growth rate for output and the growth rate for intensity. For emissions to stabilize, emissions intensity must decline at a rate equal to the growth rate of output.

Allowing firms in an intensity limited *TEP*'s system to buy cheap sequestration offsets will further increase net emissions. If sequestration offsets can be sold into an Intensity based system relatively cheaply, it may be necessary to adjust the intensity target downward more and/or sooner in order to avoid the growth in net emissions. Alan and Bayliss (2005) have pointed out that the inability to guarantee absolute emission levels makes the European Emissions Trading System (EETS), with its absolute cap, hesitant to trade with systems using intensity targets. The EETS is also suspicious of sinks, because of the difficulty in ensuring net removals. It is shown here that even if sinks do constitute net removals, they can exacerbate the tendency of intensity based systems to increase emissions as output increases.

Regardless of whether an absolute or intensity based system is used, the marginal cost of sequestration relative to the $15/tonne price assurance mechanism is likely to limit the purchases of offsets by large final emitters.

A better alternative would be to allow offsets credits and/or a price assurance mechanism in combination with an Absolute cap on emissions. This would provide reduced marginal abatement costs without increased emissions.

Table 1: Simulation Results: No Sequestration

Absolute Cap: No Sequestration

	B=18				B=26			
Cap	**Intensity**	**Emissions**	**MAC**	**Marginal**	**Intensity**	**Emissions**	**MAC**	**Marginal**
A	**u*1**	**u*1Q*1**	**c'(u1*)**	**Damages**	**u*1**	**u*1Q*1**	**c'(u1*)**	**Damages**
12	2.65	12	2.7	0	1.81	12	4.38	0
14	2.82	14	2.36	2.36	2	14	4	2.36
16	2.98	16	2.04	2.41	2.18	16	3.64	2.41
18	3.1	18	1.8	2.46	2.33	18	3.34	2.46
20	3.22	20	1.56	2.51	2.48	20	3.04	2.51
22	3.34	22	1.32	2.56	2.62	22	2.76	2.56
24	3.45	24	1.1	2.61	2.74	24	2.52	2.61
26	3.56	26	0.88	2.66	2.86	26	2.28	2.66
28	3.65	28	0.7	2.71	2.98	28	2.04	2.71
30	3.75	30	0.5	2.76	3.08	30	1.84	2.76
32	3.84	32	0.32	2.81	3.18	32	1.64	2.81
34	3.92	34	0.16	2.86	3.28	34	1.44	2.86
36	4	36	0	2.91	3.37	36	1.26	2.91
38	4	38	0	2.96	3.46	38	1.08	2.96
40	4	40	0	3.01	3.55	40	0.9	3.01
42	4	42	0	3.06	3.63	42	0.74	3.06

Intensity Cap: No Sequestration

	B=18				B=26			
Cap	**Intensity**	**Emissions**	**MAC**	**Marginal**	**Intensity**	**Emissions**	**MAC**	**Marginal**
u	**u*2**	**u*2Q*2**	**c'(u2*)**	**Damages**	**u*2**	**u*2Q*2**	**c'(u2*)**	**Damages**
2.82	2.82	23.42	1.17	2.36	2.82	34.7	1.37	2.36

Table 2: Simulation Results: With Sequestration

Absolute Cap: WIth Sequestration

B=18

Cap A	Intensity uº1	Emissions uº1Qº1	MAC c'(u1º)	Marginal Damages	Sequestration m1
12	3.5	24.96	1	0	12.96
14	3.5	24.96	1	2.36	10.96
16	3.5	24.96	1	2.41	8.96
18	3.5	24.96	1	2.46	6.96
20	3.5	24.96	1	2.51	4.96
22	3.5	24.96	1	2.56	2.96
24	3.5	24.96	1	2.61	0.96
26	3.56	31.68	0.88	2.66	5.68
28	3.65	32.63	0.7	2.71	4.63
30	3.75	33.64	0.5	2.76	3.64
32	3.84	34.52	0.32	2.81	2.52
34	3.92	35.28	0.16	2.86	1.28
36	4	36	0	2.91	0
38	4	36	0	2.96	0
40	4	36	0	3.01	0
42	4	36	0	3.06	0

Intensity Cap: With Sequestration

B=18

Cap u	Intensity u*2	Emissions u*2Q*2	MAC c'(u2*)	Marginal Damages	Sequestration m1	Net Emissions
2.82	3.5	29.89	1	2.61	5.81	24.08

Absolute Cap: WIth Sequestration

B=26

Cap A	Intensity uº2	Emissions uº2Qº2	MAC c'(u2º)	Marginal Damages	Sequestration m2
12	3.5	38.96	1	0	26.96
14	3.5	38.96	1	2.36	24.96
16	3.5	38.96	1	2.41	22.96
18	3.5	38.96	1	2.46	20.96
20	3.5	38.96	1	2.51	18.96
22	3.5	38.96	1	2.56	16.96
24	3.5	38.96	1	2.61	14.96
26	3.5	38.96	1	2.66	12.96
28	3.5	38.96	1	2.71	10.96
30	3.5	38.96	1	2.76	8.96
32	3.5	38.96	1	2.81	6.96
34	3.5	38.96	1	2.86	4.96
36	3.5	38.96	1	2.91	2.96
38	3.5	38.96	1	2.96	0.96
40	3.55	39.48	0.9	3.01	0
42	3.63	40.37	0.74	3.06	0

Intensity Cap: With Sequestration

B=26

Cap u	Intensity u*2	Emissions u*2Q*2	MAC c'(u2*)	Marginal Damages	Sequestration m2	Net Emissions
2.82	3.5	43.87	1	2.89	8.52	35.35

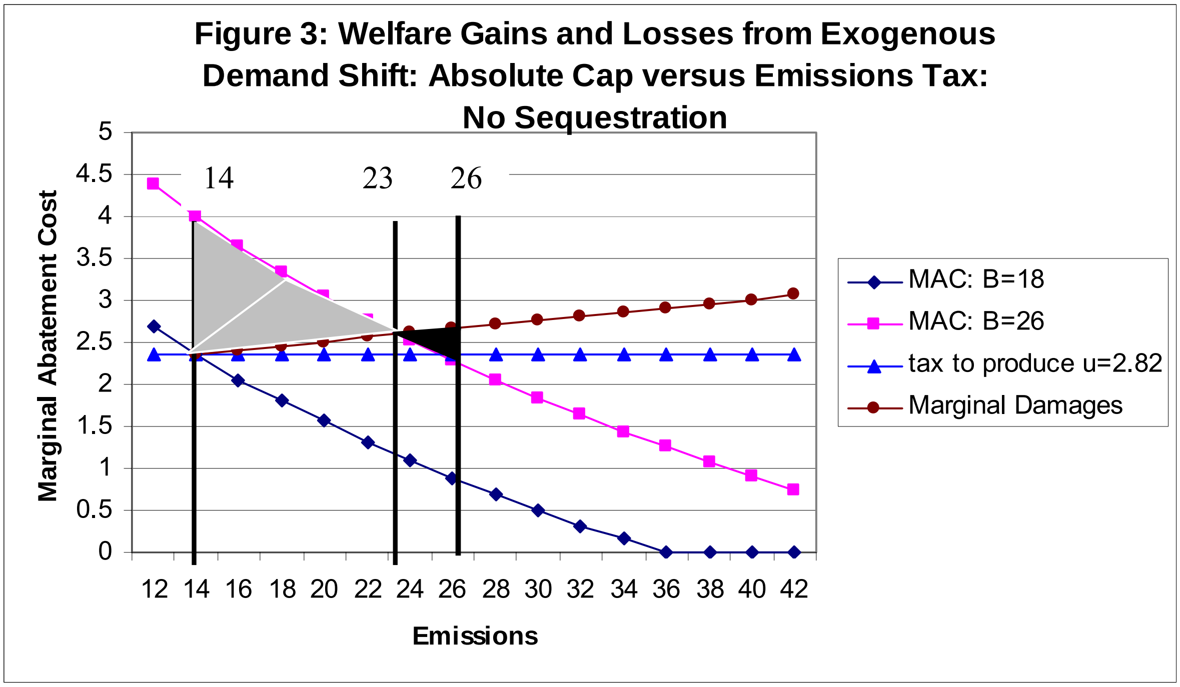


Figure 3: Welfare Gains and Losses from Exogenous Demand Shift: Absolute Cap versus Emissions Tax: No Sequestration
Marginal Abatement Cost
Emissions
14
23
26
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
MAC: B=18
MAC: B=26
tax to produce u=2.82
Marginal Damages

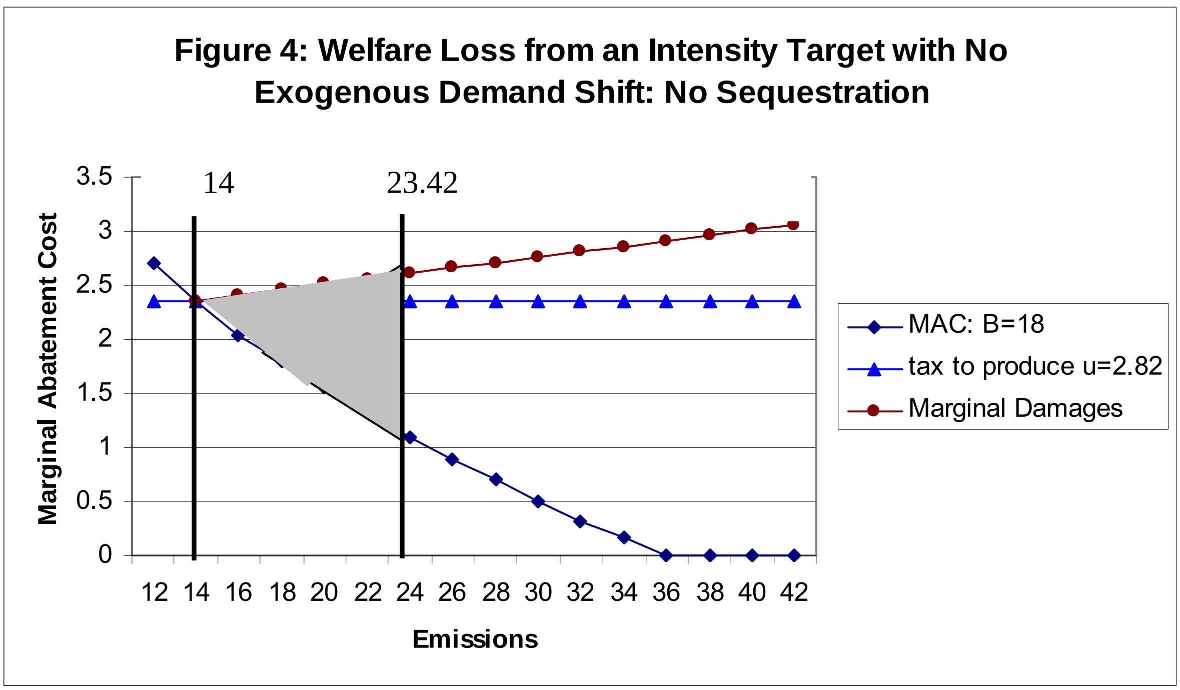


Figure 4: Welfare Loss from an Intensity Target with No Exogenous Demand Shift: No Sequestration
Marginal Abatement Cost
Emissions
14
23.42
3.5
3
2.5
2
1.5
1
0.5
0
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
MAC: B=18
tax to produce u=2.82
Marginal Damages

Figure 5: Welfare Gains and Losses from Exogenous Demand Shift: Intensity Limit: No Sequestration

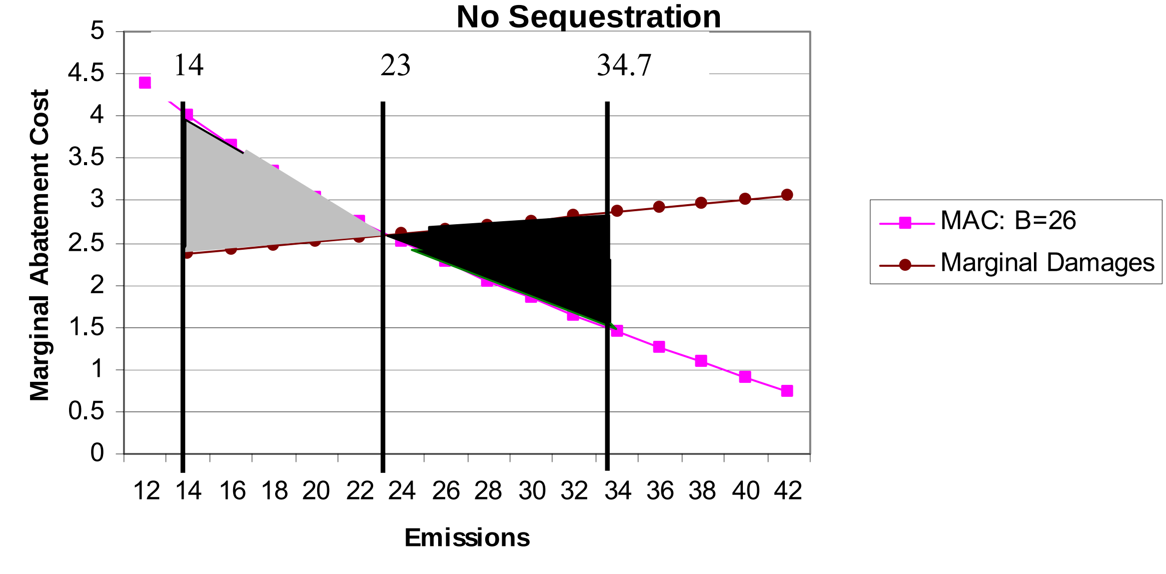
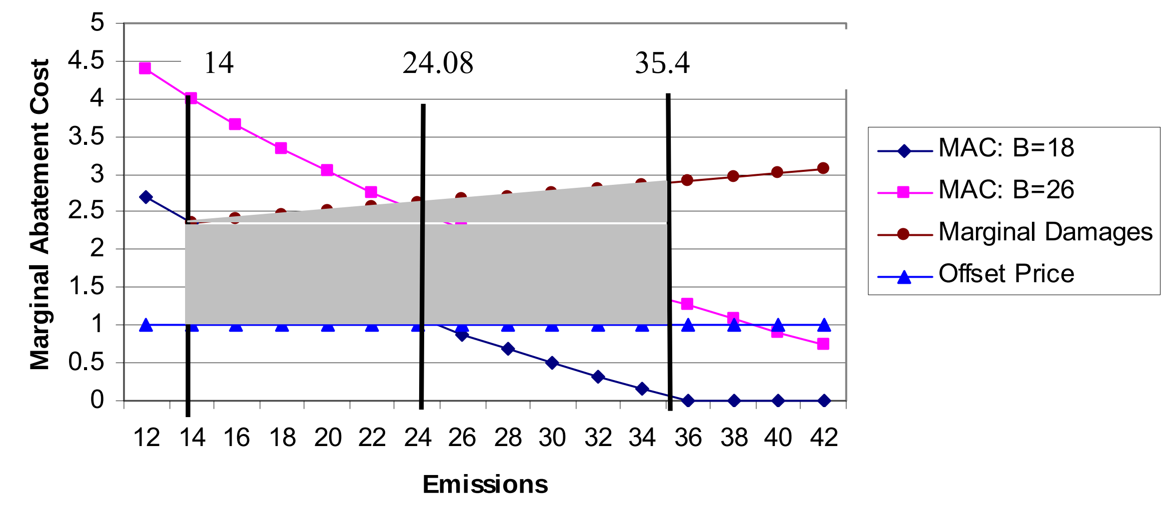


Figure 6: Welfare Losses with Itensity Limit and Cheap Sequestration.



Glossary

Emissions tax: Tax per unit of emissions, optimally equal to the MDC at the efficient level of emissions.

Emissions cap: A cap on total allowable emissions optimally set at the efficient level of emissions.
Intensity limit: A limit on the intensity of emissions per unit of output

LFE: Large final emitters

MAC: Marginal Abatement Cost: The extra abatement cost associated with an extra unit of emissions.

MDC: Marginal Damage Cost: The extra damage associated with an extra unit of emissions.

Optimal (or economically efficient) level of emissions: The level at which total damages plus total abatement costs are minimized, or at which *MDC=MAC*.

Welfare Loss: The loss to society from too many or to emissions. Too few emissions implies that *MAC>MDC* at the chosen level. Too many emissions implies that *MDC>MAC*.

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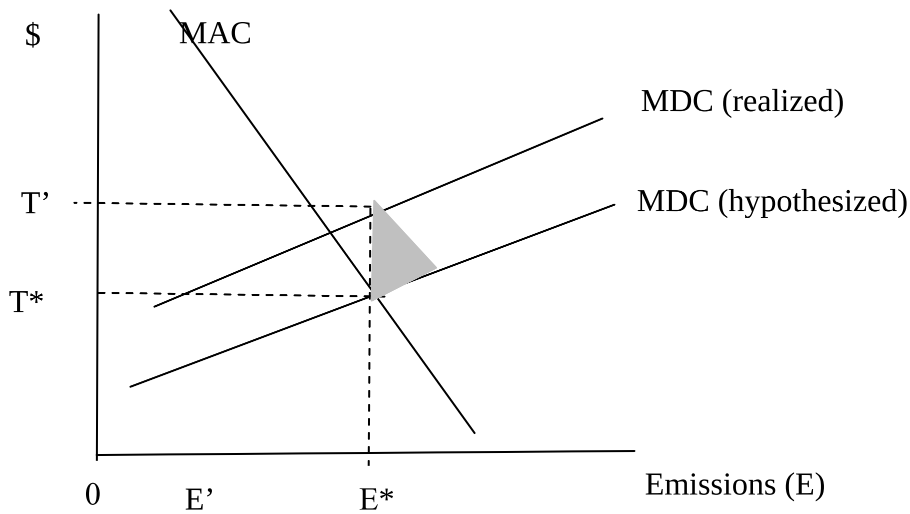
Appendix A: Uncertainty in the Marginal Damage Cost Function

Assume that a tax, *T*,* or a cap, *E**, are set based on the *MAC* and the hypothesized marginal damage function. Then a higher *MDC* is realized as shown in Figure 2. The cap *E** will result in realized *MDC* exceeding *MAC* by *T'-T** and there will be a total loss equal to the grey triangle in Figure 2. The tax *T** will lead to emissions *E** and will result in the same loss. Hence, uncertainly in the *MDC* does not affect the choice of regulatory instrument, only uncertainty in the *MAC*.

Figure A: Losses Associated with Uncertain Marginal Damage Costs



Appendix B: Emissions Intensity Concepts

The emissions performance of individual entities can be measured and monitored in two ways, in absolute terms – quantity of CO_2 emissions for the system generating the emissions (economy, industry, firm, plant, process), or in relative terms – quantity of CO_2
per some specified activity level. Whereas the former indicator is relatively straightforward, the other is more complex. It requires additional information about the efficiency of *GHG* performance of the system under consideration. Several definitions for expressing emissions rate are used in literature and by industry.

Emissions intensity is a level or amount of emissions per some unit of time, area and/or per unit of economic activity. Whereas the numerator is straightforward, there are various options for the denominator, based on the intended scope of the analysis (economy versus firms, different types of industry etc.). If economic activity is considered for denominator, then there are two possible points at which to monitor the activity: the input or output side of the system. Output measures include Gross Domestic Product *(GDP), PPP*, sales revenue, goods or energy produced. On the input side the measures include energy consumed, amount of polluting input, etc.

Some other terms used to describe this general concept of emissions intensity or its subset and broadly used are:

- *Emission coefficient,* a unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., pounds of carbon dioxide emitted per energy of fossil fuel consumed.

- *Carbon intensity,* the amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) or Joule (J) of energy.

- *Production Carbon Intensity,* a measure of the amount of CO_2 in tones per unit of production. Widely used by oil and gas industry where the production is expressed in m^3 or barrels of oil equivalents.

- *Carbon output rate,* the amount of carbon by weight per kilowatt-hour of electricity produced.
- *CO_2 intensity*, industrial CO_2 emissions per industrial GDP PPP is the amount of CO_2 emitted by the industry sector per amount of income generated by the industrial sector. [10]

These indicators and the way they are derived provide different information on the performance of firms, industry or economy as a whole and have to be clearly defined when considered as a measure for the purpose of intensity targets regimes.

[10] See eia.gov.dov and CAPP (2003) for further discussion.