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The Impact of Ex-Ante versus Ex-Post CDM Baselines on a Monopoly Firm

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Abstract: Clean Development Mechanism (CDM) baseline setting methods may be broadly classified as ex ante or ex post. Ex post baselines consider information available before and after implementation of the project. However, the incorporation of ex post information inadvertently runs the risk of distorting the incentives of project participants. Accordingly, when the scale of output is endogenously determined, an ex post baseline tends to boost output. We show that this may increase total emissions, despite the reduction in emissions per output. With an ex ante baseline, output is suppressed, bringing about the benefit of a reduction in total emissions. However, lower output implies a decrease in consumer and producer surplus. Consequently, total social welfare may actually deteriorate because of the CDM.

Keywords: Clean Development Mechanism (CDM), baseline, monopoly, welfare, leakage

1. INTRODUCTION

1.1. CDM and Baseline Methodology

The Clean Development Mechanism (CDM) was introduced by the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) that was negotiated in 1997 and came into effect in February 2005. The baseline for a CDM project is intended to capture the emissions that would have prevailed were it not for the project.

Baseline setting methods may be broadly classified as ex ante and ex post. Laurikka [2002] and Imai and Akita [2003], for instance, have previously examined the differences between the ex ante and ex post baseline methodologies and their risk implications for CDM project investment incentives. More specifically, both Laurikka [2002] and Imai and Akita [2003] assume that the greenhouse gas (GHG) emission level hx is proportional to output level x, where h is a constant rate of emissions per unit of output, and output x is stochastic and exogenous. A CDM project then reduces the emission coefficient from its previous level h to $\tilde{h}$ ($< h$) such that the ex ante baseline is $b = \mathrm{E}[hx] = h\mathrm{E}[x]$ while the ex post baseline is $b = hx$. The fundamental difference between the ex ante and ex post schemes is then that the amount of CDM credit generated under the ex ante baseline scheme $b - \tilde{h}x = hE[x] - \tilde{h}x$ is decreasing in output x, while under the ex post scheme, $b - \tilde{h}x = hx - \tilde{h}x = (h - \tilde{h})x$ is increasing in x. (Further exploration of these issues can be found in Imai, Akita, and Niizawa (2008) as well as in Fischer (2005).)

1.2. Ex Post Baseline and Output Scale Choice

When output is endogenously determined, the ex post baseline tends to have a higher scale of output and thus a higher level of emissions. Any increase in CDM-induced output may then be regarded as constituting a form of self-leakage. When the output-enhancing effect more than offsets the reduction in per output emissions, we have the perverse case of a counterproductive CDM. We illustrate this possibility using a simple model of a monopolistic firm facing a demand curve with constant price elasticity. We show that the more competitive the output good market, the greater the CDM effect on output. This makes the perverse case of a counterproductive CDM more likely.

1.3. Ex Ante Baseline and Economic Welfare

The profit-maximizing scale of output under an ex ante CDM baseline is smaller than its pre-CDM level. Therefore, under the ex ante baseline scheme, we need not be troubled by the counterproductive CDM project. Instead, we should be more generally concerned with overall social welfare encompassing consumer and producer surplus. We show that the CDM project may in fact reduce total social surplus from its pre-CDM level depending on the valuation of unit emissions reductions. (This case corresponds to the standard textbook case of Pigovian tax levied on a monopolist firm. C.f. Baumol and Oates () and also Kolstad ().)

2. THE MODEL

2.1. Equilibrium Output without and with a CDM

2.1.1. Without CDM

Consider a monopolistic firm in a non-Annex I developing country. Let the firm be faced with an inverse demand function $P(x) = x^{\frac{-1}{\varepsilon}}$, where *x* is output and " is a constant price elasticity of demand. For simplicity, let the firm have a constant marginal production cost c (> 0) and a constant rate *h* (> 0) of GHG emissions per unit of output. The firm is subject to no obligation for an emissions reduction. Thus, without a CDM, the profit of the firm is given by $\pi = P(x)x - cx = x^{\frac{\varepsilon-1}{\varepsilon}} - cx$, and this is independent of its emissions level *hx*. The optimal levels of output and emissions are then given as follows.

Lemma 1 (No CDM) Consider a monopolistic firm with constant marginal production cost *c* and an inverse demand function $P(x) = x^{\frac{-1}{\varepsilon}}$, where " (> 1) is a constant price elasticity of demand. The optimal output level with no CDM is given by $x^{no-CDM} \equiv \left(\dfrac{\varepsilon}{\varepsilon - 1} c \right)^{-\varepsilon}$.

2.1.2. With CDM

Suppose the firm is now engaged in a CDM project that reduces emissions per unit of output from *h* to $\tilde{h}$ (< *h*) and increases the constant level of marginal production costs from *c* to $\tilde{c}$ (> *c*). The CDM project grants the firm credits for any reduction in emissions $b - \tilde{h}x$, where *b* is the emissions baseline, and $\tilde{h}x$ is the actual emissions level associated with output *x*. For simplicity, we assume the firm maximizes total profits given by $\pi = P(x)x - \tilde{c}x + \rho(b - \tilde{h}x) = x^{\frac{\varepsilon-1}{\varepsilon}} - \tilde{c}x + \rho(b - \tilde{h}x),$ where ρ is the market price of emissions credit.

Ex Ante Baseline The ex ante baseline is given by $b^{exante} \equiv hx^{no-CDM}$. Firm profit then becomes $\pi^{exante} = x^{\frac{\varepsilon-1}{\varepsilon}} - \tilde{c}x + \rho(hx^{no-CDM} - \tilde{h}x),$ and the optimal levels of output and emissions are given as follows.

Lemma 2 (Ex Ante Baseline) Consider a monopolistic firm with constant marginal production cost *c* and an inverse demand function $P(x) = x^{\frac{-1}{\varepsilon}}$, where " is a constant price elasticity of demand. The optimal output level with a CDM and an ex ante baseline is $b^{exante} \equiv hx^{no-CDM}$, and the emissions reduction credit price ρ is given by $x^{exante} \equiv \left(\dfrac{\varepsilon}{\varepsilon - 1} \left(\tilde{c} + \rho\tilde{h} \right) \right)^{-\varepsilon} < x^{no-CDM}$. As a consequence, equilibrium output is unambiguously lower than its pre-CDM level.

Ex post Baseline The ex post baseline is given by $b^{\exp ost} \equiv hx$. Firm profit then becomes $\pi^{\exp ost} = x^{\frac{\varepsilon-1}{\varepsilon}} - \tilde{c}x + \rho(h - \tilde{h}).$ The optimal levels of output and emissions are given as follows.

Lemma 3 (Ex Post Baseline) Consider a monopolistic firm with constant marginal production cost *c* and an inverse demand function $P(x) = x^{\frac{-1}{\varepsilon}}$, where " is a constant price elasticity of demand. The optimal output level $x^{\exp ost}$ with a CDM and an ex post baseline is $b^{\exp ost} \equiv hx$, and the emissions reduction credit price ρ is given by $x^{\exp ost} \equiv \left(\frac{\varepsilon}{\varepsilon - 1} \left(\tilde{c} - \rho(h - \tilde{h}) \right) \right)^{-\varepsilon}$.

2.2. Self-leakage and a Counterproductive CDM under an Ex Post Baseline

We now focus our attention on the ratio of the actual emissions level $\tilde{h}x^{\exp ost}$ under an ex post baseline scheme to the emissions level $hx^{no-CDM} (= b^{exante})$ that would prevail without the CDM. If the value of this ratio exceeds unity, we have the perverse situation of a counterproductive CDM.

Lemma 4 (Actual Emissions under Ex Post Baseline) The actual emissions level $\tilde{h}x^{\exp ost}$ under an ex post baseline scheme relative to the emissions level $hx^{no-CDM} (= b^{exante})$ that would prevail without the CDM is given by $f(z, y, \delta, \varepsilon) \equiv \frac{\tilde{h}x^{\exp ost}}{hx^{no-CDM}} = z(y - \delta(1-z))^{-\varepsilon}$, where $z \equiv \frac{\tilde{h}}{h} \leq 1, y \equiv \frac{\tilde{c}}{c} \geq 1, \delta \equiv \frac{\beta h}{c} \geq 0.$ We further assume $y - \delta(1-z) \geq 0$ for any 2*z* [0; 1]. We then find
$f(0, y, \delta, \varepsilon) = 0,\ f(1, y, \delta, \varepsilon) = y^{-\varepsilon} \leq 1.$
With regard to this relative emissions function $f(z, y, \delta, \varepsilon)$ and its slope with respect to z, we find the following.

Lemma 5 (Properties of Relative Emissions Function) The relative emissions function $f(z, y, \delta, \varepsilon)$ is increasing in $z \equiv \frac{\tilde{h}}{h}$ when $0 \leq z < z^* \equiv \frac{y - \delta}{(\varepsilon - 1)\delta}$, and decreasing in z when $z^* < z \leq 1$. The slope $\frac{\partial f(z, y, \delta, \varepsilon)}{\partial z}$ is decreasing in *z* when $0 \leq z < 2z^*$, and increasing in z when $2z^* < z \leq 1$.

$$\frac{\partial f(z, y, \delta, \varepsilon)}{\partial z} \begin{cases} > 0 & if \quad 0 \leq z < z^*, \\ = 0 & if \quad z = z^* = \dfrac{y - \delta}{(\varepsilon - 1)\delta} \leq 1 \\ < 0 & if \quad z^* < z \leq 1 \end{cases}$$

$$\frac{\partial^2 f(z, y, \delta, \varepsilon)}{\partial^2 z} \begin{cases} > 0 & if \quad 0 \leq z < 2z^*, \\ = 0 & if \quad z = 2z^* \leq 1 \\ < 0 & if \quad 2z^* < z \leq 1. \end{cases}$$

Figure 1 depicts a typical profile of the function $f(z, y, \delta, \varepsilon)$ when δ = 0:4, " = 15 and *y* = 1:2. The above lemma implies the following proposition regarding the effect of an emissions reduction per unit of output on the relative emissions level.

Proposition 6 (The Effect of Per Output Emissions Reduction) When demand is sufficiently inelastic such that $z^* \equiv \frac{y - \delta}{(\varepsilon - 1)\delta}$, the relative actual emissions level $\frac{\tilde{h}x^{\exp ost}}{hx^{no-CDM}}$ monotonically decreases as $z \equiv \frac{\tilde{h}}{h}$ decreases from unity to zero. On the contrary, when demand is so elastic that $z^* \equiv \frac{y - \delta}{(\varepsilon - 1)\delta} < 1$, then the emissions level initially increases though eventually the emissions level decreases as $z \equiv \frac{\tilde{h}}{h}$ decreases from unity to zero.

In order to identify the condition under which the counterproductive CDM is possible, we now examine the behavior of $f^*(y,\delta,\varepsilon)$ as a function of demand elasticity ". The following lemma and proposition describe under what conditions perverse complete leakage becomes possible. Figure 2 depicts the profile of $f^*(y,\delta,\varepsilon)$ as a function of " when δ = 0:4, " = 15 and *y* = 1:2.

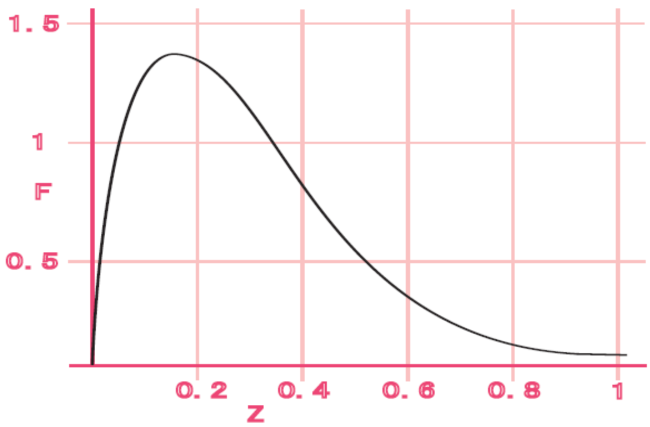

Figure 1: function $f(z, y, \delta, \varepsilon)$

Lemma 7 Let $f^*(y,\delta,\varepsilon) \equiv f(z^*, y, \delta, \varepsilon) = z^*(y-\delta(1-z^*))^{-\varepsilon} = \frac{y-\delta}{(\varepsilon-1)\delta}\left((y-\delta)\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}$,

where $z^* \equiv \frac{y-\delta}{(\varepsilon-1)\delta} < 1$. Then $f^*(y,\delta,\varepsilon) = \max_{z\in[0,1]} f(z,y,\delta,\varepsilon)$ when $z^* \equiv \frac{y-\delta}{(\varepsilon-1)\delta} \le 1$; i.e., $\frac{y}{\delta} \le \varepsilon$. Regarding $f^*(y,\delta,\varepsilon)$, we find the following results.

$$f^*(y,\delta,\frac{y}{\delta}) = y^{-\varepsilon} \le 1.$$

$$y-\delta \ge 1 \Rightarrow \left[\begin{array}{c} \lim_{\varepsilon\to+\infty} f^*(y,\delta,\varepsilon) = 0 \\ \frac{\partial f^*(y,\delta,\varepsilon)}{\partial \varepsilon} < 0 \; for \varepsilon \in (1,+\infty). \end{array}\right.$$

$$0 \le y-\delta < 1 \Rightarrow \left[\begin{array}{c} \lim_{\varepsilon \to +\infty} f^*(y,\delta,\varepsilon) = +\infty \\ \dfrac{\partial f^*(y,\delta,\varepsilon)}{\partial \varepsilon} \begin{cases} \le 0 \; for \varepsilon \in (1, \dfrac{1}{1-(y-\delta)}] \\ > 0 \; for \varepsilon \in (\dfrac{1}{1-(y-\delta)}, +\infty) \end{cases} \end{array} \right. .$$

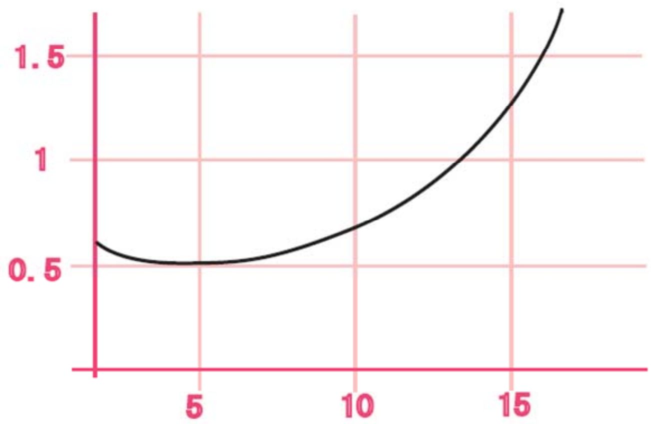

Figure 2: profile of of $f^*(y, \delta, \varepsilon)$

Proposition 8 If $y-\delta \ge 1$, the maximum relative emissions level $\max_{z\in[0,1]} f(z,y,\delta,\varepsilon)$ never exceeds unity for any demand elasticity " > 1, and is monotonically decreasing in " for $\varepsilon \ge \dfrac{y}{\delta}$. If $0 < y-\delta < 1$, $\max_{z\in[0,1]} f(z,y,\delta,\varepsilon)$ is initially decreasing and subsequently increasing in ", and its value exceeds unity when the demand elasticity is sufficiently large.

2.3. Output Suppression and Total Economic Welfare under an Ex Ante Baseline

We now examine the impact on total economic welfare. This consists of not only the benefit of the reduction in emissions but also the impact on consumer and producer surplus. For the sake of simplicity, we assume that the market price ρ of a unit emissions reduction credit properly measures the social benefit of a unit emissions reduction.

2.3.1. Welfare before CDM

We first consider total welfare before the CDM.

Lemma 9 (Social Welfare before CDM) Total social welfare before the CDM is given by $W^{no-CDM} = \int_{x=0}^{x=x^{no-CDM}} (p(x)-c)dx = \frac{2\varepsilon-1}{\varepsilon(\varepsilon-1)}(x^{no-CDM})^{\frac{\varepsilon-1}{\varepsilon}}$, where " > 1 is a constant demand elasticity and $x^{no-CDM} \equiv \left(\frac{\varepsilon}{\varepsilon-1}c\right)^{-\varepsilon}$.

2.3.2. Welfare under an Ex Ante Baseline

We now turn to social welfare under the CDM with an ex ante baseline.

Lemma 10 (Social Welfare under a CDM with an ex ante baseline) Total social welfare under a CDM with an ex ante baseline is given by $W^{exante} = \int_{x=0}^{x=x^{exante}} (p(x)-\tilde{c})dx + \rho(hx^{no-CDM} - \tilde{h}x^{exante}) = \frac{2\varepsilon-1}{\varepsilon(\varepsilon-1)}(x^{exante})^{\frac{\varepsilon-1}{\varepsilon}} + \rho h x^{no-CDM}$, where " > 1 is a constant demand elasticity and $x^{exante} \equiv \left(\frac{\varepsilon}{\varepsilon-1}\left(\tilde{c}+\rho\tilde{h}\right)\right)^{-\varepsilon}, x^{no-CDM} \equiv \left(\frac{\varepsilon}{\varepsilon-1}c\right)^{-\varepsilon}$.

2.3.3. Output Suppression and Welfare Change

We are now ready to examine how the CDM project with an ex ante baseline changes total social welfare. First, we examine the dependence of $\frac{W^{exante}}{W^{no\text{-}CDM}}$ on ρ.

Lemma 11 (Dependence of Welfare on ρ) With regard to the change in total social welfare from $W^{no\text{-}CDM}$ to W^{exante}, we find the following.

$$\frac{W^{exante}}{W^{no\text{-}CDM}} = \left(\frac{\tilde{c}+\rho\tilde{h}}{c}\right)^{1-\varepsilon} + \frac{\rho h}{c}\frac{(\varepsilon-1)^2}{2\varepsilon-1}, \left.\frac{W^{exante}}{W^{no\text{-}CDM}}\right|_{\rho=0} = \left(\frac{\tilde{c}}{c}\right)^{1-\varepsilon} \leq 1,$$

$$\frac{d}{d\rho}\left(\frac{W^{exante}}{W^{no\text{-}CDM}}\right) = (\varepsilon-1)\frac{h}{c}\left[\frac{\varepsilon-1}{2\varepsilon-1} - \left(\frac{\tilde{c}+\rho\tilde{h}}{c}\right)^{-\varepsilon}\frac{\tilde{h}}{h}\right]$$

$$\left.\frac{d}{d\rho}\left(\frac{W^{exante}}{W^{no\text{-}CDM}}\right)\right|_{\rho=0} = (\varepsilon-1)\frac{h}{c}\left[\frac{\varepsilon-1}{2\varepsilon-1} - \left(\frac{\tilde{c}}{c}\right)^{-\varepsilon}\frac{\tilde{h}}{h}\right].$$

$$\frac{d^2}{d^2\rho}\left(\frac{W^{exante}}{W^{no\text{-}CDM}}\right) = (\varepsilon-1)\varepsilon\left(\frac{\tilde{c}+\rho\tilde{h}}{c}\right)^{-(\varepsilon+1)}\left(\frac{\tilde{h}}{c}\right)^2 > 0$$

Second, we summarize our main result in the following proposition.

Proposition 12 (Ex Ante Baseline and Welfare Change) When the social valuation ρ (> 0) of the unit emissions reduction is sufficiently small, total social welfare W^{exante} is necessarily less than its pre-CDM level, $W^{no\text{-}CDM}$. Furthermore, if demand is sufficiently inelastic, such that $\frac{\varepsilon-1}{2\varepsilon-1}\left(\frac{\tilde{c}}{c}\right)^{\varepsilon} < \frac{\tilde{h}}{h}(\leq 1)$, then W^{exante} is initially decreasing in ρ. That is, the CDM project can reduce total social welfare inclusive of the social benefit of an emissions reduction if output demand is sufficiently inelastic and the social valuation of the unit emissions reduction is sufficiently small.

3. CONCLUSION

We have examined the implications of endogenous output scale determination under an ex post CDM baseline on total emissions. When the per output emissions level falls, the ex post baseline may well increase output. This output-enhancing effect constitutes a form of self-leakage. We have shown that self-leakage is likely to emerge when the demand elasticity is sufficiently large. When h reduces to $\tilde{h}$, the self-leakage effect may increase output, and this may lead to an increase in total emissions despite the reduction in per output emissions. We have shown that this counterproductive CDM is likely to arise when the demand elasticity is sufficiently high.

In contrast, an ex ante baseline tends to suppress output and thus can never increase the level of total emissions. However, this tendency to suppress output may not be entirely costless. We find that the CDM may harm welfare if output demand is sufficiently small and the social valuation of the unit emissions reduction is sufficiently small.

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