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PREEMPTION BY BASELINE

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ABSTRACT
The Clean Development Mechanism (CDM) is a project based mechanism introduced by the Kyoto protocol (1997). Among other unsettled issues pertaining to CDM, this paper explores a dynamic implication of CDM baseline. A continuous time dynamic duopoly model of an incumbent firm and an entrant firm is constructed. We show that CDM baseline plays an important role when the incumbent (leader) and the entrant (follower) choose their timing of CDM project investments. Because of the baseline, the entrant's investment with higher technological potential gets postponed, while the incumbent invests earlier than otherwise.

KEY WORDS: Climate Change, Kyoto Protocol, CDM, Timing Game

MSC: 91B76

RESUMEN
El Mecanismo de desarrollo de Limpieza (Clean Development Mechanism (CDM)) es un proyecto basado en el mecanismo introducido por el protocolo de Kyoto (1997). Entre otros aspectos no fijados pertenecientes al CDM, este trabajo explora la implicación dinámica de la base del CDM . Un modelo de duopolio dinámico a tiempo continuo de una firma incumbente y una firma entrante es construido. Mostramos que la base del CDM juega un rol importante cuando la firma incumbente (líder) y la entrante (seguidor) seleccionan sus tiempos de inversión en el proyecto CDM. Como la base, la inversión de la firma entrante con major potencial tecnológica es pospuesta, mientras la incumbente invierte mas temprano en todo caso.

1 INTRODUCTION

The Clean Development Mechanism (CDM) is a project based mechanism introduced by the Kyoto protocol (1997) to UNFCCC. One may deem it as an attempt to convert emission reduction in countries without emission reduction commitments including developing countries and some developed countries (mostly former socialist counties) into emission reduction usable toward the fulfillment of the quantified emission reduction commitments by the Annex I (or B) developed countries. CDM is more than a mere emission reduction subsidy scheme. It involves immense complexity and conceptual difficulty, which made some people question its functionality (See Bohm and Carlen (2002) for example).

Nevertheless, the number of registered projects has exceeded 1000 by 2008. Expected amount of CDM credits including ones "in the pipeline", i.e. proposed but not yet authorized credits have reached 1.2 billion tones by 2008. Some speculate that this may be just enough to fill the demand-supply gap in the emission trade under Kyoto protocol (2008-2012). (For a general overview of the current state of CDM, see Capoor and Ambrosi (2008) , Lecocq and Ambrosi (2007) for instance.) Initially, many developing countries were skeptical of the mechanism, but they appear to be more interested now. Categories of projects eligible for CDM has expanded to encompass programmable CDM, policy CDM, sector CDM etc. On the other hand, some parties have grown weary of the burdensome procedure of CDM, and proposed to simplify the scheme. CDM has launched successfully, but room for further controversy remains.

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The present authors have previously raised the issue of CDM baseline methodologies. (Imai and Akita (2002). We analyzed the issue in the context of static oligopoly game (Imai, Akita, and Niizawa (2008)). This paper deals with dynamic duopoly and focuses on firms' incentive to invest in technology associated with CDM projects. Researchers agree that technological breakthrough is the key to combating the climate change. Desire for technology transfer has been an important driving force for project based mechanisms. Youngman et al (2007), and de Coninck et. al. (2007) estimate how much CDM has contributed to technology transfer. Hagem (2009) examines the baseline issue in the context of duopoly, highlighting the contrast between CDM and cap-and-trade scheme. This paper, on the other hand, focuses on firm's incentive for technology development in dynamic duopoly of an incumbent firm and an entrant firm. We explore how the incumbent's CDM investment timing interacts with that of the entrant's entry and CDM investment capable of even further technology improvement. We previously found that a preceding CDM project tends to discourage subsequent CDM projects in most oligopoly. (Imai, Akita, and Niizawa (2007)). In what follows, we show how the firms' investment timings interact through the CDM baseline.

2. MODEL DESCRIPTION AND ASSUMPTIONS

We consider an infinite horizon continuous time model of CDM investment timing game played by an incumbent monopolist firm and an entrant firm. The incumbent firm has a monopoly before the entrant enters. After the entry, the two firms complete a la Cournot.

2.1. Emissions Reduction Investments

The incumbent chooses when to make a CDM investment to reduce its own GHG emission coefficient down to $e(1)$. The investment cost in present discount value is $I\exp\left(-(\delta+r)t_m\right)$ if made at time t_m. The entrant chooses when to enter and make a CDM investment that reduces its own coefficient down to $e(2)\left(< e(1)\right)$. The firm cannot enter without investing. The investment cost in present discount value is $J\exp\left(-(\delta+r)t_e\right)$ if made at time t_e. The interest rate $r\left(>0\right)$ is constant. The investment costs in current value decay at a constant rate $\delta\left(>0\right)$.

2.2. Ex-Post Baseline

Baseline faced by a CDM project is supposed to capture what emission could have happened was it not for the project. In practice, so-called "ex-post" Imai and Akita (2003), or "rate-based"(Fischer (2005)) ir "relative" (Laurika (2002)) CDM baseline has been predominantly used in actual CDM methodologies. According to this approach, the ex-post emission baseline is not a fixed number, but varies proportionally with ex-post output scale q. Suppose a CDM investment reduces emissions coefficient from its initial level $e(0)$ down to $e(1)$. Then the ex-post baseline is $e(0)q$, which presumes that the same ex-post output level would have happened with or without the project.

2.3. The Baseline Effect

What would have happened without a CDM project by a firm is generally affected by preceding CDM projects by other firms. In designing the operational specifics of CDM institution, one could postulate that a preceding emission reduction project defines the baseline faced with by subsequent projects. We shall call this "the baseline effect".

Suppose the entrant invests and enters after the incumbent already invested. The incumbent has reduced the emission coefficient from $e(0)$ to $e(1)$. Emission reduction achieved by the incumbent is $e(0)q_m - e(1)q_m = xq_m$ where $x \equiv e(0) - e(1)\,(\geq 0)$ is the reduction in the emission coefficient and q_m is the incumbent's ex post output. The entrant enters and invests to reduced the coefficient further down to $e(2)$. With the baseline effect, the entrant's baseline is $e(1)q_e$ rather than $e(0)q_e$ where q_e is the entrant's ex post output. The entrant's emission reduction is $e(1)q_e - e(2)q_e = yq_e$ where $y \equiv e(1) - e(2)\,(\geq 0)$. Without the baseline effect, the baseline is $e(0)q_e$, and emission reduction is $e(0)q_e - e(2)q_e = (x + y)q_e$.

Suppose the incumbent invests after the entrant already invested. The entrant has reduced the coefficient from $e(0)$ to $e(2)$. Its emission reduction is $e(0)q_e - e(2)q_e = (x + y)q_e$. Then the incumbent invests to achieve the emission coefficient of $e(1)$. Without the baseline effect, the baseline is $e(0)q_m$, and emission reduction is $e(0)q_m - e(1)q_m = xq_m$. With the baseline effect, however, the applicable baseline is $e(2)q_m$ rather than $e(0)q_m$. Thus, emission reduction is $\max\{0, e(2)q_m - e(1)q_m\} = 0$.

Suppose the incumbent invests simultaneously with the entrant. Neither firm has no predecessor and the baseline effect is irrelevant. The incumbent's baseline is $e(0)q_m$, and the entrant's baseline is $e(0)q_e$, with or without the baseline effect.

2.4. Investment Timing, Emissions Reduction Credit, Firms' Payoffs

Both the incumbent and the entrant have zero production cost. They are faced with an inverse demand function $p = 1 - Q = 1 - (q_m + q_e)$. Every unit of emission reduction sells at the market price of $\lambda\,(> 0)$. Firm's profit consists of output sales and emissions reduction credit sales. The latter depends on the incumbent's investment timing t_m, the entrant's timing t_e and the baseline effect. For example, suppose $t_m < t_e$. After the entrance, the market is duopolistic. The incumbent and the entrant choose their output q_m and q_e to maximize their respective profit taking the opponent's choice as given. With the baseline effect, the incumbent's credit sales is λxq_m, while the entrant's credit sales is λyq_e. Their optimization behaviors:

Maximize $\pi_m = pq_m + \lambda xq_m = (1 - q_m - q_e)q_m + \lambda xq_m$

Maximize $\pi_e = pq_e + \lambda yq_e = (1 - q_m - q_e)q_e + \lambda yq_e$

yield the equilibrium instantaneous profits $\pi_{3,m}$, $\pi_{3,e}$ respectively:

$$\pi_m = q_m^2 = \left(\frac{1 + \lambda(2x - y)}{3}\right)^2 \equiv \pi_{3,m}, \quad \pi_e = q_e^2 = \left(\frac{1 + \lambda(-x + 2y)}{3}\right)^2 \equiv \pi_{3,e}.$$

Different timings lead to different emission reduction credit and instantaneous profits that accrue to each firm. The following tables summarize the firms' equilibrium profits with and without the baseline effect.

[With the Baseline Effect]

Timing			Emission Reduction Credit			Instantaneous Profit		
	t_m		0	λxq_m	λxq_m	π_0	π_1	$\pi_{3,m}$
		t_e	/	/	λyq_e	/	/	$\pi_{3,e}$

$\begin{array}{\|c\|c\|} \hline & t_m \\ \hline & t_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|} \hline 0 & \lambda x q_m \\ \hline / & \lambda(x+y)q_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|} \hline \pi_0 & \pi_{4,m} \\ \hline / & \pi_{4,e} \\ \hline \end{array}$
$\begin{array}{\|c\|c\|c\|} \hline & & t_m \\ \hline & t_e & \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline 0 & 0 & 0 \\ \hline / & \lambda(x+y)q_e & \lambda(x+y)q_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline \pi_0 & \pi_{2,m} & \pi_{2,m} \\ \hline / & \pi_{2,e} & \pi_{2,e} \\ \hline \end{array}$

[Without the Baseline Effect]

Timing	Emission Reduction Credit	Instantaneous Profit
$\begin{array}{\|c\|c\|c\|} \hline & t_m & \\ \hline & & t_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline 0 & \lambda x q_m & \lambda x q_m \\ \hline / & / & \lambda(x+y)q_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline \pi_0 & \pi_1 & \pi_{4,m} \\ \hline / & / & \pi_{4,e} \\ \hline \end{array}$
$\begin{array}{\|c\|c\|} \hline & t_m \\ \hline & t_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|} \hline 0 & \lambda x q_m \\ \hline / & \lambda(x+y)q_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|} \hline \pi_0 & \pi_{4,m} \\ \hline / & \pi_{4,e} \\ \hline \end{array}$
$\begin{array}{\|c\|c\|c\|} \hline & & t_m \\ \hline & t_e & \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline 0 & 0 & \lambda x q_m \\ \hline / & \lambda(x+y)q_e & \lambda(x+y)q_e \\ \hline \end{array}$	$\begin{array}{\|c\|c\|c\|} \hline \pi_0 & \pi_{2,m} & \pi_{4,m} \\ \hline / & \pi_{2,e} & \pi_{4,e} \\ \hline \end{array}$

$$\text{where} \quad \begin{array}{l} \pi_0 \equiv \frac{1}{4} \\ \pi_1 = \frac{(1+\lambda x)^2}{4} \\ \pi_{2,m} = \left(\frac{1-\lambda(x+y)}{3}\right)^2, \pi_{2,e} = \left(\frac{1+2\lambda(x+y)}{3}\right)^2 \\ \pi_{3,m} = \left(\frac{1+\lambda(2x-y)}{3}\right)^2, \pi_{3,e} = \left(\frac{1+\lambda(-x+2y)}{3}\right)^2 \\ \pi_{4,m} = \left(\frac{1+\lambda(x-y)}{3}\right)^2, \pi_{4,e} = \left(\frac{1+\lambda(x+2y)}{3}\right)^2 \end{array} \quad \text{with} \quad \begin{array}{l} \pi_1 \geq \pi_0 \\ \pi_{3,m} \geq \pi_{4,m} \geq \pi_{2,m} \\ \pi_{3,e} \leq \pi_{4,e} \leq \pi_{2,e} \end{array} .$$

Before the entry, the incumbent's monopoly profit with reduction credit (π_1) is greater than that without credit (π_0). After the entry, the incumbent's profit is smallest ($\pi_{2,m}$) when only the entrant has invested, and largest when only the incumbent has invested ($\pi_{3,m}$) with the baseline effect is present. When the investment is simultaneous, or without the baseline effect, duopoly profits are $\pi_{4,m}$, $\pi_{4,e}$ respectively.

2.5. Leader's Payoff, Follower's Payoff

Cumulative present discount value of the instantaneous profit flow combined with one shot CDM investment cost defines the firms' payoffs.

2.5.1. When the incumbent firm is the leader: $t_m < t_e$

When the incumbent invests before the entrant, payoff $L_m(t_m)$ of the incumbent as the leader and payoff $F_e(t_m)$ of the entrant as the follower are given as follows.[2] We regard them as functions of the leader's timing t_m, though $F_e(t_m)$ actually does not involve t_m. The follower's timing t_e is chosen by the entrant to maximize its subsequent payoff.

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[2] The notation and the conceptual framework to analyze the timing game draws heavily on Fudenberg, D. and Tirole, J. (1985).

[With the Baseline Effect]

$$L_m(t_m) \equiv \int_0^{t_m} \pi_0 e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{t_e} \pi_1 e^{-rt} dt + \int_{t_e}^{\infty} \pi_{3,m} e^{-rt} dt$$

$$F_e(t_m) \equiv -Je^{-(\delta+r)t_e} + \int_{t_e}^{\infty} \pi_{3,e} e^{-rt} dt$$

$$t_e = \arg\max_{\hat{t}_e} \left[-Je^{-(\delta+r)\hat{t}_e} + \int_{\hat{t}_e}^{\infty} \pi_{3,e} e^{-rt} dt \right] = \max\{t_m, t_e^*\}, \quad t_e^* \equiv \frac{1}{\delta} \ln \frac{J(\delta+r)}{\pi_{3,e}}$$

[Without the Baseline Effect]

$$L_m(t_m) \equiv \int_0^{t_m} \pi_0 e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{t_e} \pi_1 e^{-rt} dt + \int_{t_e}^{\infty} \pi_{4,m} e^{-rt} dt$$

$$F_e(t_m) \equiv -Je^{-(\delta+r)t_e} + \int_{t_e}^{\infty} \pi_{4,e} e^{-rt} dt$$

$$t_e = \arg\max_{\hat{t}_e} \left[-Je^{-(\delta+r)\hat{t}_e} + \int_{\hat{t}_e}^{\infty} \pi_{4,e} e^{-rt} dt \right] = \max\{t_m, t_e^*\}, \quad t_e^* \equiv \frac{1}{\delta} \ln \frac{J(\delta+r)}{\pi_{4,e}}$$

2.5.2. When the entrant firm is the leader: $t_e < t_m$

When the entrant invests before the incumbent, payoff $F_m(t_e)$ of the incumbent as the follower, and payoff $L_e(t_e)$ of the entrants as the leader are given as follows. We regard them as functions of the leader's timing t_e. The follower's timing t_m is chosen by the incumbent to maximize its subsequent payoff. In particular, we note that $t_m = +\infty$ with the baseline effect. We also note that $t_m^* = \frac{1}{\delta} \ln \frac{I(\delta+r)}{\pi_{4,m} - \pi_{2,m}}$ does not involve the leader's timing t_e.

[With the Baseline Effect]

$$\begin{aligned} F_m(t_e) &\equiv \int_0^{t_e} \pi_0 e^{-rt} dt + \int_{t_e}^{t_m} \pi_{2,m} e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{\infty} \pi_{2,m} e^{-rt} dt \\ &= \int_0^{t_e} \pi_0 e^{-rt} dt + \int_{t_e}^{\infty} \pi_{2,m} e^{-rt} dt - Ie^{-(\delta+r)t_m} \end{aligned}$$

$$\begin{aligned} L_e(t_e) &\equiv -Je^{-(\delta+r)t_e} + \int_{t_e}^{t_m} \pi_{2,e} e^{-rt} dt + \int_{t_m}^{\infty} \pi_{2,e} e^{-rt} dt \\ &= -Je^{-(\delta+r)t_e} + \int_{t_e}^{\infty} \pi_{2,e} e^{-rt} dt \end{aligned}$$

[Without the Baseline Effect]

$$F_m(t_e) \equiv \int_0^{t_e} \pi_0 e^{-rt} dt + \int_{t_e}^{t_m} \pi_{2,m} e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{\infty} \pi_{4,m} e^{-rt} dt$$

$$L_e(t_e) \equiv -Je^{-(\delta+r)t_e} + \int_{t_e}^{t_m} \pi_{2,e} e^{-rt} dt + \int_{t_m}^{\infty} \pi_{4,e} e^{-rt} dt$$

$$t_m = \arg\max_{\hat{t}_m} \left[\int_0^{t_e} \pi_0 e^{-rt} dt + \int_{t_e}^{\hat{t}_m} \pi_{2,m} e^{-rt} dt - Ie^{-(\delta+r)\hat{t}_m} + \int_{\hat{t}_m}^{\infty} \pi_{4,m} e^{-rt} dt \right] = \max\{t_e, t_m^*\}$$

$$t_m^* = \frac{1}{\delta} \ln \frac{I(\delta+r)}{\pi_{4,m} - \pi_{2,m}}$$

2.5.3. When the incumbent and the entrant invest simultaneously: $t_e = t_m$

When the incumbent and the entrant invest simultaneously at $t_e = t_m = t_B$, their payoff $B_m(t_B)$, $B_e(t_B)$ are given as follows.

$$B_m(t_B) \equiv \int_0^{t_B} \pi_0 e^{-rt} dt - Ie^{-(\delta+r)t_B} + \int_{t_B}^{\infty} \pi_{4,m} e^{-rt} dt$$

$$B_e(t_B) \equiv -Je^{-(\delta+r)t_B} + \int_{t_B}^{\infty} \pi_{4,e} e^{-rt} dt$$

3. EQUILIBRIUM WITH EPSILON PREEMPTION

We now focus our attention to characterize an equilibrium in which the incumbent invests before the entrant invests and enters.

3.1. Entrant's Incentive Constraint

3.1.1. Entrant's Incentive Constraint

Given that the incumbent firm is the leader, i.e. $t_m < t_e$, we have seen that the entrant optimally chooses $t_e = \max\{t_m, t_e^*\}$ to maximize $F_e(t_m)$. However, the entrant might as well attempt to forestall the incumbent by investing at $t_e = t_m - \varepsilon$ where the lead margin $\varepsilon \geq 0$ is chosen optimally. Thus, we need consider an incentive constraint to thwart such an attempt.

3.1.2. Simultaneous Investment is Suboptimal

If the entrant chooses $\varepsilon = 0$, her payoff is $B(t_m)$. But this choice is suboptimal with the baseline effect since $\lim_{\varepsilon\to 0} L_e(t_m - \varepsilon) \geq B_e(t_m)$. The baseline effect gives an advantage to the leader and a disadvantage to the follower. It is better to invest slightly earlier to acquire the leader's advantage. Without the baseline effect, we have $\lim_{\varepsilon\to 0} L_e(t_m - \varepsilon) = B_e(t_m)$ and the choice between zero and positive infinitesimal margin is immaterial.

3.1.3. Infinitesimal Lead versus Non-infinitesimal Lead

Having ruled out $\varepsilon = 0$, it remains to check whether the entrant should choose infinitesimal lead margin $\varepsilon \cong 0$ or non-infinitesimal $\varepsilon > 0$. We recall that the entrant chooses the lead margin $\varepsilon > 0$ to maximize $L_e(t_m - \varepsilon)$. Payoff of the entrant as the leader:

[With the Baseline Effect]

$$L_e(t_e) = -Je^{-(\delta+r)t_e} + \int_{t_e}^{\infty} \pi_{2,e} e^{-rt} dt$$

[Without the Baseline Effect]

$$L_e(t_e) \equiv -Je^{-(\delta+r)t_e} + \int_{t_e}^{t_m} \pi_{2,e} e^{-rt} dt + \int_{t_m}^{\infty} \pi_{4,e} e^{-rt} dt$$

$$\text{with } \quad t_m = \max\{t_e, t_m^*\}, \quad t_m^* = \frac{1}{\delta} \ln \frac{I(\delta + r)}{\pi_{4,m} - \pi_{2,m}}$$

is maximized at $t_e = t_e^{**} \equiv \frac{1}{\delta} \ln \frac{J(\delta + r)}{\pi_{2,e}}$ unless $t_e > t_m^*$. Thus, if $t_e^{**} < t_m$, then the entrant chooses $\varepsilon > 0$ such that $t_e = t_m - \varepsilon = t_e^{**}$. If $t_m \leq t_e^{**}$, the entrant choose an infinitesimal $\varepsilon \cong 0$ to attain $t_e \cong t_m \leq t_e^{**}$. Therefore, we have

$$\max_{\varepsilon} L_e(t_m-\varepsilon)=\begin{cases} L_e(t_e^{**}) & \text{if } t_e^{**}\le t_m \\ L_e(t_m) & \text{if } t_m<t_e^{**} \end{cases} \qquad : \ t_e^{**}\equiv\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{2,e}}$$

3.1.4. The Incumbent's Timing that Discourages the Entrant's Challenge

In order to discourage the entrant from forestalling the incumbent, $F_e(t_m)\ge \max_{\varepsilon} L_e(t_m-\varepsilon)$ must hold. Recalling:

[With the Baseline Effect]

$$F_e(t_m)=-Je^{-(\delta+r)t_e^*}+\int_{t_e^*}^{\infty}\pi_{3,e}e^{-rt}dt=-Je^{-(\delta+r)t_e^*}+\pi_{3,e}\frac{e^{-rt_e^*}}{r} \qquad : t_e^{*}\equiv\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{3,e}},$$

$$L_e(t_m)=-Je^{-(\delta+r)t_e}+\int_{t_e}^{\infty}\pi_{2,e}e^{-rt}dt\bigg|_{t_e=t_m}=-Je^{-(\delta+r)t_m}+\pi_{2,e}\frac{e^{-rt_m}}{r},$$

[Without the Baseline Effect]

$$F_e(t_m)=-Je^{-(\delta+r)t_e^*}+\int_{t_e^*}^{\infty}\pi_{4,e}e^{-rt}dt=-Je^{-(\delta+r)t_e^*}+\pi_{4,e}\frac{e^{-rt_e^*}}{r} \qquad : \ t_e^{*}\equiv\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{4,e}},$$

$$L_e(t_m)=\left[-Je^{-(\delta+r)t_e}+\int_{t_e}^{t_m}\pi_{2,e}e^{-rt}dt+\int_{t_m}^{\infty}\pi_{4,e}e^{-rt}dt\right]\Bigg|_{t_e=t_m}=-Je^{-(\delta+r)t_m}+\pi_{4,e}\frac{e^{-rt_m}}{r},$$

we find

[With the Baseline Effect]

$$F_e(t_m)-L_e(t_m)=\left[-Je^{-(\delta+r)t_e^*}+\pi_{3,e}\frac{e^{-rt_e^*}}{r}\right]-\left[-Je^{-(\delta+r)t_m}+\pi_{2,e}\frac{e^{-rt_m}}{r}\right],$$

[Without the Baseline Effect]

$$F_e(t_m)-L_e(t_m)=\left[-Je^{-(\delta+r)t_e^*}+\pi_{4,e}\frac{e^{-rt_e^*}}{r}\right]-\left[-Je^{-(\delta+r)t_m}+\pi_{4,e}\frac{e^{-rt_m}}{r}\right].$$

Furthermore, we find

[With the Baseline Effect]

$$t_e^{**}\equiv\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{2,e}}<\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{3,e}}\equiv t_e^* \quad \text{since} \quad \pi_{2,e}>\pi_{3,e},$$

$$F_e(t_e^*)-L_e(t_e^*)=(\pi_{3,e}-\pi_{2,e})\frac{e^{-rt_e^*}}{r}<0,$$

[Without the Baseline Effect]

$$t_e^{**}\equiv\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{2,e}}<\frac{1}{\delta}\ln\frac{J(\delta+r)}{\pi_{4,e}}\equiv t_e^* \quad \text{since} \quad \pi_{4,e}\le\pi_{2,e},$$

$$F_e(t_e^*)-L_e(t_e^*)=0.$$

We find that the timing t_e^{**} that maximizes $L_e(t_e)$ arrives before t_e^*, where $F_e(t_e^*)-L_e(t_e^*)$ is negative (with the baseline effect) or zero (without the baseline effect). This indicates that the incentive constraint $F_e(t_m)\ge \max_{\varepsilon} L_e(t_m-\varepsilon)$ does not automatically hold and the constraint demands that the incumbent's timing t_m be sufficiently early.

3.2. The Incumbent's Optimal Investment Timing

3.2.1 The Incumbent's Problem

In the equilibrium of our interest, the incumbent chooses her investment timing t_m to maximize $L_m(t_m)$ subject to the entrant's incentive constraint $F_e(t_m) \geq \max_\varepsilon L_e(t_m - \varepsilon)$ or $F_e(t_m) \geq L_e(t_m)$ provided that $t_m \leq t_e^{**}$.

[With the Baseline Effect]

$$L_m(t_m) = \int_0^{t_m} \pi_0 e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{t_e^*} \pi_1 e^{-rt} dt + \int_{t_e^*}^{\infty} \pi_{3,m} e^{-rt} dt \ : \ t_e^* = \frac{1}{\delta} \ln \frac{J(\delta + r)}{\pi_{3,e}}$$

[Without the Baseline Effect]

$$L_m(t_m) = \int_0^{t_m} \pi_0 e^{-rt} dt - Ie^{-(\delta+r)t_m} + \int_{t_m}^{t_e^*} \pi_1 e^{-rt} dt + \int_{t_e^*}^{\infty} \pi_{4,m} e^{-rt} dt : \ t_e^* = \frac{1}{\delta} \ln \frac{J(\delta + r)}{\pi_{3,e}}$$

The objective function $L_m(t_m)$ attains the global maximum at $t_m^{**} \equiv \frac{1}{\delta} \ln \frac{I(\delta + r)}{\pi_1 - \pi_0}$ if we disregard the incentive constraint. We find $L_m^{'}(t_m) > 0$ for $t_m < t_m^{**}$ and $L_m^{'}(t_m) < 0$ for $t_m > t_m^{**}$ with or without the baseline effect.

3.2.2. Binding Incentive Constraint of the Entrant

If $F_e(t_m^{**}) \geq L_e(t_m^{**})$, then the constraint does not bind at the unconstrained optimum. Thus, the incumbent's optimal choice is $t_m = t_m^{**}$ provided that $t_m^{**} \leq t_e^{**}$. If $F_e(t_m^{**}) < L_e(t_m^{**})$, then the incentive constraint binds at the unconstrained optimum, and the incumbent must invest at some earlier timing t_m such that $F_e(t_m) = L_e(t_m)$, $t_m \leq t_e^{**}$. Thus we find the following results.

Case 1) If the entrant's investment cost J satisfies the following conditions:

[With the Baseline Effect]

$$J \geq \frac{\pi_{2,e} e^{r(t_e^* - t_m^{**})} - \pi_{3,e}}{r(e^{(\delta+r)(t_e^* - t_m^{**})} - 1) e^{-\delta t_e^*}} > 0 \ : t_e = \frac{1}{\delta} \ln \frac{J(\delta + r)}{\pi_{3,e}}$$

[Without the Baseline Effect]

$$J \geq \frac{\pi_{4,e} (e^{r(t_e^* - t_m^{**})} - 1)}{r(e^{(\delta+r)(t_e^* - t_m^{**})} - 1) e^{-\delta t_e^*}} > 0 \ : t_e = \frac{1}{\delta} \ln \frac{J(\delta + r)}{\pi_{4,e}}$$

then the incumbent should invest at $t_m^{**} \equiv \frac{1}{\delta} \ln \frac{I(\delta + r)}{\pi_1 - \pi_0}$ provided that $t_m^{**} \leq t_e^{**}$.

Case 2) If the entrant's investment cost J satisfies the following conditions:

[With the Baseline Effect]

$$\frac{\pi_{2,e} e^{r(t_e^* - t_m^{**})} - \pi_{3,e}}{r(e^{(\delta+r)(t_e^* - t_m^{**})} - 1) e^{-\delta t_e^*}} > J > \frac{\pi_{2,e} e^{r t_e^*} - \pi_{3,e}}{r(e^{(\delta+r)t_e^*} - 1) e^{-\delta t_e^*}}$$

[Without the Baseline Effect]

$$\frac{\pi_{4,e} (e^{r(t_e^* - t_m^{**})} - 1)}{r(e^{(\delta+r)(t_e^* - t_m^{**})} - 1) e^{-\delta t_e^*}} > J > \frac{\pi_{4,e} (1 - e^{-r t_e^*})}{r(1 - e^{-(\delta+r) t_e^*})}$$

then the incumbent should invest slightly before a timing t_m such that $F_e(t_m) = L_e(t_m)$ and $t_m \leq t_e^{**}$ just as early enough to keep the entrant as the follower. This is the case of epsilon preemption, in which we are primarily interested.

Case 3) If the entrant's investment cost J satisfies the following conditions:

[With the Baseline Effect]

$$J < \frac{\pi_{2,e} - \pi_{3,e} e^{-rt_e^*}}{r(1 - e^{-(\delta+r)t_e^*})}$$

[Without the Baseline Effect]

$$J < \frac{\pi_{4,e}(1 - e^{-rt_e^*})}{r(1 - e^{-(\delta+r)t_e^*})}$$

then the incumbent cannot meet the entrant's incentive condition by investing earlier.

3.3. The Incumbent's Incentive Constraint

As long as the entrant's incentive constraint is satisfied, the entrant will invest at t_e^* and the incumbent's payoff is $L_m(t_m)$. For this to be an equilibrium, the incumbent should have no incentive to abandon its position as the leader. If the incumbent invests simultaneously at t_e^*, its payoff is $B_m(t_e^*)$. If it invests strictly after t_e^*, then its payoff is $F_m(t_e^*)$. Thus, we must require $L_m(t_m) \geq \max\{F_m(t_e^*), B_m(t_e^*)\}$. Hence, we have the following conditions.

[With the Baseline Effect]

$$L_m(t_m) - F_m(t_e^*) = -Ie^{-(\delta+r)t_m} + (\pi_1 - \pi_0)\frac{e^{-rt_m} - e^{-rt_e^*}}{r} + (\pi_{3,m} - \pi_{2,m})\frac{e^{-rt_e^*}}{r} \geq 0$$

if $Ie^{-\delta t_e^*} > \frac{\pi_{4,m} - \pi_{2,m}}{r}$

$$L_m(t_m) - B_m(t_e^*) = (\pi_1 - \pi_0)\frac{e^{-rt_m} - e^{-rt_e^*}}{r} + (\pi_{3,m} - \pi_{4,m})\frac{e^{-rt_e^*}}{r} - I\left(e^{-(\delta+r)t_m} - e^{-(\delta+r)t_e^*}\right) \geq 0$$

if $Ie^{-\delta t_e^*} \leq \frac{\pi_{4,m} - \pi_{2,m}}{r}$

[Without the Baseline Effect]

$$L_m(t_m) - F_m(t_e^*) = -Ie^{-(\delta+r)t_m} + (\pi_1 - \pi_0)\frac{e^{-rt_m} - e^{-rt_e^*}}{r} + (\pi_{3,m} - \pi_{2,m})\frac{e^{-rt_e^*}}{r} \geq 0$$

if $I > \frac{\pi_{4,m} - \pi_{2,m}}{r} \frac{e^{-rt_e^*} - e^{-rt_m^*}}{e^{-(\delta+r)t_e^*} - e^{-(\delta+r)t_m^*}}$

$$L_m(t_m) - B_m(t_e^*) = (\pi_1 - \pi_0)\frac{e^{-rt_m} - e^{-rt_e^*}}{r} - I\left(e^{-(\delta+r)t_m} - e^{-(\delta+r)t_e^*}\right) \geq 0$$

if $I \leq \frac{\pi_{4,m} - \pi_{2,m}}{r} \frac{e^{-rt_e^*} - e^{-rt_m^*}}{e^{-(\delta+r)t_e^*} - e^{-(\delta+r)t_m^*}}$

3.4. The Consequences of the Baseline Effect

With regard to Case 3 of section 3.2., recall that the incumbent invests at t_m such that $F_e(t_m) - L_e(t_m) \geq 0$ is barely satisfied. Then the entrant's potential challenge against the incumbent's leader status is successfully epsilon-preempted. We now seek to identify how the preemption condition is affected by the presence or absence of the baseline effect. For this purpose, we compare $F_e(t_m) - L_e(t_m)$ with and without the baseline effect.

[With the Baseline Effect]

$$F_e(t_m) - L_e(t_m) = \left[-Je^{-(\delta+r)t_e^*} + \pi_{3,e} \frac{e^{-rt_e^*}}{r} \right] - \left[-Je^{-(\delta+r)t_m} + \pi_{2,e} \frac{e^{-rt_m}}{r} \right] \equiv \Psi_B(t_m)$$

where $t_e^* = \frac{1}{\delta} \ln \frac{J(\delta+r)}{\pi_{3,e}} \equiv \tau_B$

[Without the Baseline Effect]

$$F_e(t_m) - L_e(t_m) = \left[-Je^{-(\delta+r)t_e^*} + \pi_{4,e} \frac{e^{-rt_e^*}}{r} \right] - \left[-Je^{-(\delta+r)t_m} + \pi_{4,e} \frac{e^{-rt_m}}{r} \right] \equiv \Psi_{NB}(t_m)$$

where $t_e^* = \frac{1}{\delta} \ln \frac{J(\delta+r)}{\pi_{4,e}} \equiv \tau_{NB}$

First, we recall $\pi_{3,e} \le \pi_{4,e}$ to find $\tau_B \ge \tau_{NB}$. The optimal timing of the entrant as the follower is delayed when the baseline effect is absent. Second, we recall $\pi_{3,e} \le \pi_{4,e} \le \pi_{2,e}$ to find:

$$\Psi_B(t_m) - \Psi_{NB}(t_m)$$
$$= \frac{\delta}{r(\delta+r)} \left[\pi_{3,e} \left(\frac{\pi_{3,e}}{J(\delta+r)} \right)^{\frac{r}{\delta}} - \pi_{4,e} \left(\frac{\pi_{4,e}}{J(\delta+r)} \right)^{\frac{r}{\delta}} \right] - \frac{(\pi_{2,e} - \pi_{4,e})e^{-rt_m}}{r} < 0.$$

so that $\Psi_B(t_m) \ge 0 \Rightarrow \Psi_{NB}(t_m) \ge 0$. That is, the entrant's incentive constraint $F_e(t_m) - L_e(t_m) \ge 0$ is more stringent in the presence of the baseline effect. With the baseline effect, the incumbent's investment timing t_m becomes earlier than otherwise.

The intuition behind this result is straightforward. The baseline effect generally works in favor of the leader by imposing more demanding baseline to the follower. As a result, the entrant as the follower has a stronger incentive to become the leader by forestalling the incumbent. To offset this stronger incentive, the incumbent must invest earlier to discourage the challenge.

4. CONCLUSIONS

After years of trial and errors, CDM has proven fairly successful. But room for further discussion remains. We still have issues to be sort out with regard to CDM and project-based mechanisms in general. One such issue pertains to CDM baseline. In this paper, we examined how the incumbent's investment timing interacts with that of the entrant's. The baseline plays an important role by providing advantage to the leader and disadvantage to the follower. With the baseline effect, the entrant as the follower postpones investment because of lowered income from the emission reduction credit. The baseline effect reinforces the entrant's incentive to challenge the incumbent's position as the leader. The incumbent, in turn, must invest earlier than otherwise to thwart such an attempt. On the one hand, the incumbent's earlier investment is a good news. On the other hand, that the entrant's investment in project with even further technology improvement is postponed is detrimental to combating the climate change. The analysis of overall welfare effect is beyond the scope of the present paper. However, it clearly deserves further scrutiny.

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