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Dynamic Bargaining and CDM Low Hanging Fruits with Endogenous Total Emission Abatement Target

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Abstract: A three-stage dynamic model of climate change negotiation featuring developed and developing country is constructed in order to capture Copenhagen COP of UNFCCC and subsequent developments. In stage 1 (Copenhagen), countries negotiate a long-run (total) emission abatement target $T(=q+Q+Q^{'})$, leaving specific terms of agreement undecided. In stage 2 (CDM), they negotiate emission reduction obligation q that only the developed country bears. In stage 3 (post-CDM), both countries bear abatement obligation and negotiate their respective abatement obligations $Q^{'},Q$. As they engage in stage 1 and 2 negotiations, they cannon commit themselves for period 2 abatement, which leads to the well-known problem of incomplete contract. We associate this situation with so-called CDM Low Hanging Fruits problem. We examine the gain and loss on the part of the developing country to see if their low-hanging fruits are indeed shortchanged.

Keywords: *Climate Change, Kyoto Mechanisms*

1. INTRODUCTION

Under the UNFCCC Kyoto Protocol, non-Annex I developing countries are encouraged to take part in CDM (Clean Development Mechanism). Yet developing countries are afraid of harvesting their cheapest abatement options prematurely for CDM because such options may become more valuable when they join the Annex I camp with emissions abatement obligations. Practitioners have called this apprehension Low Hanging Fruits (LHF) problem, and researchers have attempted to make sense of this. (See Castro (2010) for a survey.) The literature, however, has by and large found out that LHF apprehension is hard to rationalize without recourse to some form of myopia. Rose, Blute and Folmer (1999) showed that exploiting cheaper abatement options today for CDM is not all that harmful to a country determined to join the Annex I group tomorrow. Akita (2003) elaborated the role of technology development options. Narain and Van't Veld (2008) confirmed that rational decision precludes LHF problem. Brecht et. al. (2004) showed that a myopic country may suffer LHF problem when current emission raises future quota by a fixed proportion. The present paper builds on Akita et. al (2012) to re-approach the puzzle from dynamic bargaining perspective, setting aside individual irrationality. There is a well-known dilemma associated with dynamic bargaining. Investment contract puts a party bearing investment cost now into a weaker bargaining position unless some arrangement is made to preclude renegotiation after the investment is done. This leads to suboptimal investment or no investment at all. Grout (1984) showed that the same happens with wage bargaining. Tadenuma (2004) showed that climate change negotiation is inefficient if parties first negotiate the total amount of emission reductions, and then its allocation to the participants.

2. THE MODEL

Consider a potential CDM host country (a developing country) and a CDM investor country (a developed country) engaged in negotiation in three logical stages over two periods of time. Stages 1 and 2 take place in the beginning of period 1. In stage 1, they negotiate total emission reduction T that they jointly achieve by the end of period 2. In stage 2, they negotiate CDM in which only developed country assumes reduction obligation q but can use CDM to meet the obligation. In stage 3, they negotiate emissions trading in which both countries assume emission reduction obligations Q (developed country), Q' (developing country) and trade their abatements. In stages 1 and 2, they negotiate (T,q), knowing that they will be negotiating (Q,Q') such that $q+Q+Q'=T$ in stage 3.[1] Should either stage fall through, T is no longer respected. The failure is irrevocable so that stage 3 negotiation is impossible without first clearing stages 1 and 2.

Reduction Obligation	Host	Investor	Total
Period 1	0	q	$0+q=q$
Period 2	Q	Q'	$Q+Q'=T-q$

Let e and $E-e$ denote emission abatement by developing country in periods 1 and 2. Likewise, e' and $E'-e'$ denote emission abatement by developing country. For CDM and emission trading market to clear, we must have $e+e'=q$ and $(E-e)+(E'-e')=Q+Q'$.

Emissions Reduction	Host	Investor	Total Reduction
Period 1	e	e'	$e+e'=q=T-(Q+Q')$
Period 2	$E-e$	$E'-e'$	$(E-e)+(E'-e')=Q+Q'$

We assume that low marginal cost abatement opportunities harvested in the first CDM period are no longer available in the second ET period.[2] Accordingly, periods 1 and 2 abatement costs are respectively $\frac{c}{2}e^2$ and

[1] We assume, as in Rose et. al. (1999), that the developing country is prepared to negotiate accepting emission abatement responsibility in the second stage. Otherwise, there will be no CDM Low Hanging Fruits apprehension to begin with.

[2] See Narain et. al. (2007) for analogous assumption.

$\frac{c}{2}E^2 - \frac{c}{2}e^2$ for developing country, $\frac{k}{2}e'^2$ and $\frac{k}{2}E'^2 - \frac{k}{2}e'^2$ for developed country. We assume $c < k$, i.e., ceteris paribus, developing country has lower marginal abatement cost.

Abatement Cost	Host	Investor	
Period 1	$\frac{c}{2}e^2$	$\frac{k}{2}e'^2$	$c < k$
Period 2	$\frac{c}{2}E^2 - \frac{c}{2}e^2$	$\frac{k}{2}E'^2 - \frac{k}{2}e'^2$	

Assume that countries have linear valuation of emission abatement. [3] Combined emission abatement yields environmental benefits to both countries but at different rates. Developing country benefits for periods 1 and 2 are $r\left(e+e'\right)$ and $R\left(\left(E-e\right)+\left(E'-e'\right)\right)$. Likewise for developed country. We assume $r < R$ and $r' > R'$ so that developing country is fond of delayed action while developed country prefers early action.[4]

Environmental Benefit	Host	Investor
Period 1	$r\left(e+e'\right)$	$r'\left(e+e'\right)$
Period 2	$R\left(\left(E-e\right)+\left(E'-e'\right)\right)$	$R'\left(\left(E-e\right)+\left(E'-e'\right)\right)$
	$r < R$	$r' > R'$

In period 2, private firm profit maximization equates marginal abatement costs cE, kE' to P , which in conjunction with $E + E' = T$ yields $P = \dfrac{T}{\Delta}$ where $\Delta \equiv \dfrac{1}{c} + \dfrac{1}{k}$. In period 1 likewise CDM equates ce, ke' to p ,[5] which in conjunction with $e + e' = q$ yields $p = \dfrac{q}{\Delta}$.

CDM/ET Revenue	Host	Investor	
Period 1	$p\left(e-0\right)$	$p\left(e'-q\right)$	$p = \dfrac{q}{\Delta}$
Period 2	$P\left(\left(E-e\right)-Q\right)$	$P\left(\left(E'-e'\right)-Q'\right)$	$P = \dfrac{T}{\Delta}$

There is no time discounting. There is no technological progress in emissions associated with CDM.[6] Then, overall payoffs $\left(u, v\right)$ to developing country and developed country are:

$$u = \left\{rq + p\left(e-0\right)\right\} + \left\{R\left(T-q\right) + P\left(\left(E-e\right)-Q\right) - \frac{c}{2}E^2\right\}$$
$$v = \left\{r'q + p\left(e'-q\right)\right\} + \left\{R'\left(T-q\right) + P\left(\left(E'-e'\right)-Q'\right) - \frac{k}{2}E'^2\right\}$$

[3] Analogous assumptions are frequently made in theoretical and/or simulation studies on climate change. See Nagashima et. al. (2009) for example.

[4] The assumption that the first period abatement contributes only to the first period benefit and not to the second period benefit is made for simplicity.

[5] This presumes absolute baseline in CDM, which may be justified in the macroscopic modeling of CDM. See Germain et. al. (2008) and also Imai et. al. (2008).

[6] One of the present author previously argued that technological progress associated with CDM experience is essential for the LHF argument to make sense. See Akita (2003).

3. FIRST BEST/EFFICIENT SOLUTION

We first identify the first best solution, i.e., Pareto efficient resource allocation that maximizes

$$u+v=\left(R+R^{'}\right)T+\left(\left(r+r^{'}\right)-\left(\left(R+R^{'}\right)\right)\right)q-\frac{c}{2}E^{2}-\frac{k}{2}E^{'2}$$

subject to $E+E^{'}=T$. The following table summarizes the results. When delayed action is socially preferred ($r+r^{'}<R+R^{'}$), it is optimal to have zero CDM. We shall see that one-shot bargaining that negotiates $\left(q,Q,Q^{'},T\right)$ at once may achieve this, while three-stage negotiation generally cannot.

$q=T$	$T=\left(r+r^{'}\right)\Delta$	if $r+r^{'}>R+R^{'}$
q indeterminate	$T=\left(r+r^{'}\right)\Delta=\left(R+R^{'}\right)\Delta$	if $r+r^{'}=R+R^{'}$
$q=0$	$T=\left(R+R^{'}\right)\Delta$	if $r+r^{'}<R+R^{'}$

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4. ONE-SHOT BARGAINING AS A NATURAL REFERENCE POINT

Countries' payoffs (u,v) in terms of $\left(q,Q,Q^{'},T\right)$ are respectively given by:

$$u=\left\{rq+\frac{q^{2}}{c\Delta^{2}}\right\}+\left\{R\left(Q+Q^{'}\right)+\frac{T}{c\Delta^{2}}\left(Q+Q^{'}\right)-\frac{TQ}{\Delta}-\frac{1}{2}\frac{T^{2}}{c\Delta^{2}}\right\}$$

$$v=\left\{r^{'}q+\frac{q^{2}}{k\Delta^{2}}(1-k\Delta)\right\}+\left\{R^{'}\left(Q+Q^{'}\right)+\frac{T}{k\Delta^{2}}\left(Q+Q^{'}\right)-\frac{TQ^{'}}{\Delta}-\frac{1}{2}\frac{T^{2}}{k\Delta^{2}}\right\}$$

while the threat point payoffs (u_0,v_0) are: $u_0=r\frac{r^{'}}{k}+R\frac{R}{c}-\frac{c}{2}\left(\frac{R}{c}\right)^{2}$, $v_0=r^{'}\frac{r^{'}}{k}+R^{'}\frac{R}{c}-\frac{k}{2}\left(\frac{r^{'}}{k}\right)^{2}$

One-shot Nash Bargaining solution solves $\underset{\left(q,Q,Q^{'},T\right)}{Max}\ (u-u_0)(v-v_0)\ \ s.t.\ \begin{cases}T=q+Q+Q^{'},\\ q\geq 0,\ Q\geq 0,\ Q^{'}\geq 0\end{cases}$.

First order conditions for the optima imply

$$\left\{r+r^{'}<R+R^{'},Q>0,Q^{'}>0\right\}\Rightarrow\left\{v-v_0=u-u_0,T=\Delta\left(R+R^{'}\right),q=0,Q>0,Q^{'}>0\right\}$$

That is, when early action is socially desirable, one-shot bargaining may well produce $q=0,T=\Delta\left(R+R^{'}\right)$ and equally split the surplus ($v-v_0=u-u_0$), unless non-negativity constraints for $\left(Q,Q^{'}\right)$ gets in the way.

5. THREE STAGE BARGAINING

5.1. Stage 3 Bargaining

Period 2 payoffs (U,V) of developing and developed country in terms of $\left(q,Q,Q^{'},T\right)$ are respectively:

$$U=R(T-q)+\frac{T}{\Delta}\left(\left(\frac{T}{c\Delta}-e\right)-Q\right)-\left(\frac{c}{2}\left(\frac{T}{c\Delta}\right)^{2}-\frac{c}{2}\left(\frac{q}{c\Delta}\right)^{2}\right)$$

$$V=R^{'}(T-q)+\frac{T}{\Delta}\left(\left(\frac{T}{k\Delta}-e^{'}\right)-Q^{'}\right)-\left(\frac{k}{2}\left(\frac{T}{k\Delta}\right)^{2}-\frac{k}{2}\left(\frac{q}{k\Delta}\right)^{2}\right)$$

with $U+V=\left(R+R^{'}\right)(T-q)-\frac{1}{2}\frac{T^{2}}{\Delta}+\frac{1}{2}\frac{q^{2}}{\Delta}$, while their threat point payoffs (U_0,V_0) are

$$U_0 = R\left(\frac{R}{c}+\frac{R^{'}}{k}-q\right)-\left(\frac{c}{2}\left(\frac{R}{c}\right)^2-\frac{c}{2}\left(\frac{q}{c\Delta}\right)^2\right),\ V_0 = R^{'}\left(\frac{R}{c}+\frac{R^{'}}{k}-q\right)-\left(\frac{k}{2}\left(\frac{R^{'}}{k}\right)^2-\frac{k}{2}\left(\frac{q}{k\Delta}\right)^2\right)$$

provided that $q \le \Delta R, q \le \Delta R^{'}$. Stage 3 bargaining solves $\max_{(Q,Q^{'})} \ (U-U_0)(V-V_0)$, which yields

$$U = \frac{X}{2}+U_0,\ V = \frac{X}{2}+V_0 \ \text{ with } X \equiv \left(R+R^{'}\right)T-\frac{1}{2}\frac{T^2}{\Delta}-\frac{c}{2}\left(\frac{R}{c}\right)^2-\frac{k}{2}\left(\frac{R^{'}}{k}\right)^2-\Delta RR^{'}.$$

5.2. Stage 1 and 2 Bargaining

Stage 1 and 2 bargaining over (T,q) shares the same threat point payoffs (u_0,v_0) with the one-shot bargaining case. Countries' payoffs are:

$$u-u_0 = \frac{q^2}{c\Delta^2}+(r-R)q+C_u \quad : C_u \equiv \frac{X}{2}+\frac{RR^{'}}{k}-\frac{rr^{'}}{k}$$

$$v-v_0 = -\frac{q^2}{c\Delta^2}+\left(r^{'}-R^{'}\right)q+C_v \quad : C_v \equiv \frac{X}{2}+\frac{k}{2}\left(\frac{R^{'}}{k}\right)^2-\frac{k}{2}\left(\frac{r^{'}}{k}\right)^2$$

provided that $q \le \Delta R, q \le \Delta R^{'}$ and $X \ge 0$, so that stage 3 negotiation should not fall through. Define

$$\varepsilon \equiv \frac{1}{2}\left[(R-r)+\left(R^{'}-r^{'}\right)\right],\ \alpha \equiv \frac{1}{2}\left[(R-r)-\left(R^{'}-r^{'}\right)\right] > 0$$

We rewrite the payoffs $(u-u_0, v-v_0)$ as: $u-u_0 = \dfrac{q^2}{c\Delta^2}-(\varepsilon+\alpha)q+C_u, v-v_0 = -\dfrac{q^2}{c\Delta^2}-(\varepsilon-\alpha)q+C_v$

Stage 1 and 2 Nash bargaining solves $\max_{(q,T)} \ (u-u_0)(v-v_0)\ \ s.t.\ \ q-T \le 0$, which calls for

$$0 = \Omega(q,\varepsilon) \equiv \left(\alpha-\frac{2q}{c\Delta^2}\right)\left[\frac{2q^2}{c\Delta^2}-2\alpha q+(C_u-C_v)\right]-\varepsilon\left[(C_u+C_v)-2\varepsilon q\right]$$

and $T = \Delta\left(R+R^{'}\right)$ provided that $q < T$. Expanding $0 = \Omega(q,\varepsilon)$ with respect to ε around $\varepsilon = 0$, we find

$$q = q_{\varepsilon=0} - \left.\frac{\frac{\partial\Omega(q,\varepsilon)}{\partial\varepsilon}}{\frac{\partial\Omega(q,\varepsilon)}{\partial q}}\right|_{\substack{\varepsilon=0\\ q_{\varepsilon=0}}}\varepsilon = q_{\varepsilon=0} - \left.\frac{C_u+C_v}{\frac{2}{c\Delta^2}\left[\frac{2q^2}{c\Delta^2}-2\alpha q+(C_u-C_v)\right]+2\left(\alpha-\frac{2q}{c\Delta^2}\right)^2}\right|_{q_{\varepsilon=0}}\varepsilon$$

where $q_{\varepsilon=0}$ solves $0 = \Omega(q,0)$ which permits three roots. Among them, $q_{\varepsilon=0} \equiv \dfrac{c\Delta^2}{2}\left(\alpha-\sqrt{\alpha^2-(C_u-C_v)}\right)$ is the smallest (and nearest to zero) root provided that it is real (i.e., $\alpha^2-(C_u-C_v) \ge 0$). Otherwise, $q_{\varepsilon=0} = \dfrac{c\Delta^2}{2}$ is the only real root. For $\varepsilon > 0$, payoffs $(u-u_0, v-v_0)$ that maximize the Nash product are:

[When $\alpha^2-(C_u-C_v) \ge 0$]

$$u-u_0 = (u-u_0)_{\varepsilon=0}+\left(\frac{C_u+C_v}{2\left(\alpha-\frac{2q_{\varepsilon=0}}{c\Delta^2}\right)}-q_{\varepsilon=0}\right)\varepsilon,\ v-v_0 = (v-v_0)_{\varepsilon=0}-\left(\frac{C_u+C_v}{2\left(\alpha-\frac{2q_{\varepsilon=0}}{c\Delta^2}\right)}+q_{\varepsilon=0}\right)\varepsilon$$

with $q_{\varepsilon=0} = \dfrac{c\Delta^2}{2}\left(\alpha-\sqrt{\alpha^2-\dfrac{2}{c\Delta^2}(C_u-C_v)}\right)$ and $(u-u_0)_{\varepsilon=0} = (v-v_0)_{\varepsilon=0} = \dfrac{C_u+C_v}{2}$.

[When $\alpha^2-(C_u-C_v)<0$]

$$u-u_0=(u-u_0)_{\varepsilon=0}-q_{\varepsilon=0}\varepsilon\,,\quad v-v_0=(v-v_0)_{\varepsilon=0}-q_{\varepsilon=0}\varepsilon$$

with $q_{\varepsilon=0}=\alpha\frac{c\Delta^2}{2}$ and $(u-u_0)_{\varepsilon=0}=C_u-\alpha^2\frac{c\Delta^2}{4}>\frac{C_u+C_v}{2}$, $(v-v_0)_{\varepsilon=0}=C_v+\alpha^2\frac{c\Delta^2}{4}<\frac{C_u+C_v}{2}$.

5.3. Low Hanging Fruits

When $\varepsilon=0$, we have $R+R^{'}=r+r^{'}$, i.e., early action is just as much socially desirable as delayed action. In this neutrality case, we have $(u(q)-u_0)+(v(q)-v_0)=C_u+C_v$ i.e., Nash frontier is linear and socially optimal q is indeterminate. As ε increases from zero, we get $R+R^{'}>r+r^{'}$, i.e., delayed action becomes more socially desirable, and efficiency calls for $q=0$ since $(u(q)-u_0)+(v(q)-v_0)=-2\varepsilon q+C_u+C_v$. However, three-stage bargaining does not set $q=0$ right away, but decreases q continuously from $q_{\varepsilon=0}\equiv\frac{c\Delta^2}{2}\left(\alpha-\sqrt{\alpha^2-(C_u-C_v)}\right)$. Thus, social welfare loss is inevitable in the vicinity of this neutrality case. How does this welfare loss gets distributed between the two countries? From developing country's viewpoint, it can be seen as a matter of whether their "low hanging fruits" LHFs are overpriced or shortchanged. As a benchmark from which to measure the loss, consider what one-shot bargaining would have achieved. When $\varepsilon>0$, one-shot bargaining attains the first best, i.e., $q=0$, $T=\Delta\left(R+R^{'}\right)$ and split the surplus equally, i.e., $v-v_0=u-u_0$ provided that $Q>0,Q^{'}>0$. Hence, $\left(\frac{C_u+C_v}{2},\frac{C_u+C_v}{2}\right)$ is the appropriate benchmark.

[When $\alpha^2-(C_u-C_v)\geq 0$ and $q_{\varepsilon=0}=\frac{c\Delta^2}{2}\left(\alpha-\sqrt{\alpha^2-\frac{2}{c\Delta^2}(C_u-C_v)}\right)$]

$$u-u_0-\frac{C_u+C_v}{2}=\left(\frac{C_u+C_v}{2\left(\alpha-\frac{2q_{\varepsilon=0}}{c\Delta^2}\right)}-q_{\varepsilon=0}\right)\varepsilon\,,\quad v-v_0-\frac{C_u+C_v}{2}=-\left(\frac{C_u+C_v}{2\left(\alpha-\frac{2q_{\varepsilon=0}}{c\Delta^2}\right)}+q_{\varepsilon=0}\right)\varepsilon$$

When $\alpha^2-(C_u-C_v)\geq 0$, developed country unambiguously suffers but developing country may possibly gain particularly when $q_{\varepsilon=0}$ is small.

[When $\alpha^2-(C_u-C_v)<0$ and $q_{\varepsilon=0}=\alpha\frac{c\Delta^2}{2}$]

$$u-u_0-\frac{C_u+C_v}{2}=\left(\frac{C_u-C_v}{2}-\alpha^2\frac{c\Delta^2}{4}\right)-q_{\varepsilon=0}\varepsilon\,,\quad v-v_0-\frac{C_u+C_v}{2}=-\left(\frac{C_u-C_v}{2}-\alpha^2\frac{c\Delta^2}{4}\right)-q_{\varepsilon=0}\varepsilon$$

When $\alpha^2-(C_u-C_v)<0$, again developed country unambiguously suffers but developing country may possibly gain particularly when $\varepsilon\equiv\frac{1}{2}\left[\left(R+R^{'}\right)-\left(r+r^{'}\right)\right]\ q_{\varepsilon=0}$ is small.

In both cases, developing country may suffer from having to put up with $q>0$ where one-shot bargaining would have attained $q=0$. This happens because three-stage negotiation does not let us make one party suffer now and get compensated later in return. When q is small, CDM transfer payment which is quadratic in q (because price p is linear in q) is dominated by environmental benefit that is linear in q. Reducing q down to zero would make developing country happy (since $r<R$) but developed country unhappy (since $r^{'}>R^{'}$). For efficiency, setting $q=0$ is optimal, and one-shot negotiation would ask developed country to put up with $q=0$ in period 1 while promising compensation in period 2. In three-stage negotiation, there is no way to pre-commit to respect such promise. Instead, developing country ends up having to reduce emissions prematurely in period 1 which irrevocably raises period 2 marginal abatement cost. She may rightfully feel that her LHFs are shortchanged.

On the other hand, in both cases, developing country may possibly gain. As ε increases from zero, total welfare decreases. To mitigate this efficiency loss, three-stage negotiation would yield q lower than $q_{\varepsilon=0}$. When $\alpha^2-(C_u-C_v)<0$, this is the primary source from which developing country can gain. When $\alpha^2-(C_u-C_v)<0$, this effect turns out to be immaterial. In this case, instead, environmental benefit effect (linear in q) gets quickly dominated by CDM transfer payment effect (quadratic in q) as q increases from zero, so that Nash product is maximized while $v-v_0<u-u_0$. Relative to the one-shot bargaining benchmark, this constitutes an important source from which developing country benefits regardless of ε. Hence, developing countries' LHFs need not be shortchanged, but actually can be overpriced.

Finally, we note that in both cases developed country, unlike developing country, unambiguously suffers.

6. DISCUSSION AND CONCLUSIONS

This paper builds on Akita et al. (2012) to examine if CDM LHF could be shortchanged or overpriced in a three stage bargaining model with endogenous total emission reduction. Stage bargaining, unlike one-shot bargaining is prone to inefficiency. We analytically showed that developing country's LHFs can get shortchanged or overpriced. This result can be construed as another unwanted side-effect of CDM, whose reform or replacement has been discussed in many policy making fronts. This paper focused on the case when delayed action is socially desirable. When early action is desirable is left for further studies.

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