Environment Cooperation between Oil exporting and Oil importing countries for Climate change

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Major instruments of climate change are focused on demand side such as carbon tax or carbon credit, however, amount of carbon emission hinges on extraction rate of fossil fuel. This paper examines strategic interaction regarding carbon tax and oil extraction rate between an oil importing country and an oil exporting country.

This paper presents the differential game model with Stackelberg feedback equilibrium which incorporates cost structure of oil extraction and utility of oil consumption and disutility of climate change in value function of both countries.

We show that carbon tax increases oil extraction rate in Stackelberg feedback equilibrium with importing country's leadership. Even in a cooperative case carbon tax's effect on extraction rate is not straightforward. We demonstrate that the balance of utility of oil consumption and disutility of climate change in respective country has a significant impact on the speed of extraction and consumption of oil. The results imply that we should design the trajectories of carbon dioxide emission and oil extraction in an integrated manner.

We demonstrate that the cost structure of oil extraction and alternative energy is key critical determinants for extraction rate and cumulative extraction and it implies that technical cooperation between oil importing countries and oil exporting countries to manage the cost structure of oil and alternative energy is important for designing policies in climate change and energy security.

Keywords: *Climate change, Petroleum production, Differential game, Carbon tax*

1. INTRODUCTION

The anthropogenic emissions of carbon dioxide are caused by the combustion of fossil fuel. Major instruments of mitigation of carbon dioxide are focused on demand side management such as carbon tax or carbon credit. However, most of oil and gas extracted from underground will be converted carbon dioxide ultimately except some chemical products. Therefore, it is important to manage the oil and gas extraction rate at oil wells to manage climate change. However, there are not many literatures which studied impact of the demand side instruments on Export's incentive of oil production in a differential game setting.

Sinn (2008) pointed out the importance of supply side approach for climate policy and argued that carbon tax designed for mitigation of carbon dioxide emission might increase emission due to acceleration of early oil extraction ("Green Paradox"). Hoel (2010) argued that there exists a sufficient level of carbon tax which will mitigate near-term carbon emission and prevent green paradox. Liski and Tahvonen (2004) pointed out rent-shifting feature of

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carbon tax and argued that carbon tax designed for climate change might transfer the rents of oil producing countries to oil importing countries. Rubio and Escrich (2001) argued that if coalition of oil importing countries takes leadership, they capture the rent of oil producing countries.

Fujiwara and Long (2010) investigated the equilibrium concepts of differential game and differentiated global Stackelberg differential game and stage-wise Stackelberg differential game and concluded that leadership gains in global game and not in stage-wise game. By using differential game model in the bilateral monopoly setting, Wirl (2011) compared price and quantity instruments for global warming in both consumer government and producer government and concluded price instrument is more effective than quantity instrument even though current practice might be quantity basis.

This paper has examined strategic interaction between an oil importing country and an oil exporting country of bilateral monopoly in the framework of differential game. We employed the model of Stackelberg feedback equilibrium with leadership of an oil importing country. We extend the previous differential game models in the literatures with two important features to provide implication for climate policy design considering incentive of supply side. Firstly, we incorporate utility of oil consumption and disutility of climate change in value functions, both of which depends on cumulative oil consumption. Secondly, the model incorporate cost structure of oil extraction and differentiate the cost of fixed part and increasing part of parameter.

In the differential game with Stackelberg leadership of importing country, we have shown that carbon tax in an oil importing country increases oil extraction rate in an oil exporting country. We also studied cooperation in terms of climate and oil extraction between an oil importing country and an oil exporting country. The results imply that carbon tax should be elaborated carefully taking account of incentive of oil extraction. We have also shown that the increase rate of extraction cost has significant impact on rate of oil extraction, and the amount of cumulative extraction in both Stackelberg case and cooperative case. We also address that the balance between utility of oil consumption and disutility of climate change in respective country has significant impact on the rate of extraction and consumption of oil. The results of this paper imply an importance of cost structure of oil and alternative energy for climate policy and security supply of oil as key parameters of policy design. It also suggests that technical cooperation between oil importing country and oil exporting country to manage the cost structure is a critical factor for designing policies in climate change and energy security.

The paper is organized as follows: After the introduction, in section 2, the model is outlined and followed by specification of cases. In section 3, analysis and implication of results are presented. In section 4, the summary of results and its implications for environment and energy policy design are addressed.

2. THE MODEL

2.1 Basic Model

This section presents basic model. There are two countries, an oil-importing country (Import) and an oil-exporting country (Export). Home imposes a specific carbon tax on imported oil to mitigate demand of oil which leads to carbon dioxide emission. The model employs feedback Stackelberg equilibrium concept with Import's leadership in a bilateral monopoly setting, because Import is able to make a credible, binding commitment to a carbon tax path.

Let Q be the cumulative oil consumption and q be the rate of consumption which is identical to the rate of extraction in Foreign in the bilateral monopoly. The dynamics of oil extraction and consumption is described as $\dot{Q}= q$.

The unit cost of extracting q is defined as a linear form $c_1 + c_2 Q$. $(c_1, c_2 > 0)$ Thus, the more the Export produces the oil, the higher the cost by assuming oil extracting cost increase linearly to cumulative oil production Q . Let $\bar{Q}$ denote the cumulative oil consumption at which the extraction cost equals the choke price, $c_1 + c_2\bar{Q} = a$. Import's inverse demand function of oil is:

$$p_c = a - bq \tag{1}$$

where p_c is the price which the consumers pay per unit of oil. The parameter a $(a>0)$ is the 'choke price,' and represents the price of alternative energy. The parameter b ($b> 0$) is the slope of the demand curve.

Let τ be a specific carbon tax rate imposed on a unit of oil. The consumer price is the sum of the producer price p and the carbon tax τ.

$$p_c = p_p + \tau$$

$$p_p = a - bq - \tau \tag{2}$$

From (1) and (2) the quantity of demand can be expressed as a function of p_p and τ:

$$q = \frac{1}{b}(a - p_p - \tau) \tag{3}$$

Thus, extraction dynamics is described as:

$$\dot{Q} = q = a - p_p - \tau \tag{4}$$

2.2 Oil importing country

Firstly, we consider the model of Import. Taking the Export's feedback extracting rule $q = q(Q)$ as given, Import chooses a feedback carbon tax rule $\tau = \tau(Q)$. The utility function of Import is:

$$U_i(Q) = \frac{1}{2b} q^2 + \tau q + (w_i - z)Q^2 \tag{5}$$

where the first term $(1/2b)\, q^2$ is consumer's surplus, the second term τq is tax revenue and the third term are utility of oil consumption $w_i Q^2$ and disutility of climate change zQ^2 respectively. We assume these utility and disutility is dependent on quadratic form of cumulative consumption Q^2 (stock externality). Substituting in (5) with $p_p = a - \tau - bq$ from (2) yealds:

$$U_i(Q) = \frac{1}{2b}(a - \tau - p_p)^2 + \frac{\tau}{b}(a - \tau - p_p) + (w_i - z)Q^2$$

The Hamilton- Jacobi- Bellman (HJB) equation is defined as:

$$r V_i(Q) = \max_{\tau} \{ U_i(Q) + V_i'(Q) q \} \tag{6}$$

where $V_i(Q)$ is Import's value function and r is discount rate.

We assume linear quadratic value function for Import and Export as $V_i(Q)=A_iQ^2 + B_iQ + C_i$. Let us define $F_i = U_i(Q) + V_i'\ q$:

$$F_i(Q)= \frac{1}{2b} q^2 + \tau q + (w_i - z)Q^2$$

$$= \frac{1}{2b}(a - \tau - p_p)^2 + \frac{\tau}{b}(a - \tau - p_p) + (w_i - z)\,Q^2 + V_i'\ (Q)\frac{1}{b}\left(a - \tau - p_p\right) \quad (7)$$

The first order condition with regard to τ yields:

$$\frac{\partial F_i}{\partial \tau} = -\frac{1}{b}(a - \tau - p_p) + \frac{1}{b}\left(a - \tau - p_p\right) - \frac{\tau}{b} - \frac{1}{b} V_i'\ (Q) = 0$$

The strategy of Import is:

$$\tau(Q) = -V_i'\ (Q) = -2A_iQ - B_i \quad (8)$$

We assume linear Export's strategy as $q\ (Q) = \alpha Q + \beta$ to maximize its discounted stream of utility. Substituting these into the HJB equation of Import:

$$r(A_iQ^2 + B_iQ + C_i) = \frac{1}{2b} q^2 + \tau q + (w_i - z)Q^2$$

$$= \frac{1}{2b}(\alpha Q + \beta)^2 - (\alpha Q + \beta)(2A_iQ + B_i) + (w_i - z)Q^2 \quad (9)$$

By equating the coefficients of both sides with regard to Q^2 , Q and constant term, we have:

$$rA_i = (\frac{1}{2b}\alpha^2 - 2\alpha A_i + w_i - z) \quad (10)$$

$$rB_i = (\frac{1}{b}\alpha\beta - 2\alpha A_i + \alpha B_i) \quad (11)$$

$$rC_i = (\frac{1}{2b}\beta^2 - \beta B_i) \quad (12)$$

$$A_i = \frac{1}{r+2\alpha}(\frac{1}{2b}\alpha^2 + w_i - z) \quad (13)$$

$$B_i = \frac{1}{r-\alpha}\{\frac{1}{b}\alpha\beta - 2\alpha\frac{1}{r+2\alpha}(\frac{1}{2b}\alpha^2 + w_i - z)\} \quad (14)$$

$$C_i = \frac{1}{r}[\frac{1}{2b}\beta^2 - \beta\ \frac{1}{r-\alpha}\{\frac{1}{b}\alpha\beta - 2\alpha\frac{1}{r+2\alpha}(\frac{1}{2b}\alpha^2 + w_i - z)\}] \quad (15)$$

2.3 Oil exporting country

Oil exporting country (Export) chooses its extraction rate q, given the demand curve and carbon tax rate τ of oil importing country (Import). The utility function of Export is:

$$U_e(Q) = \{\ p_p - (c_1 + c_2\ Q)\}\ q + (w_e - z)Q^2 \quad (16)$$

where the term $(w_e - z)\ Q^2$ is utility of oil production and disutility regarding climate change. The Hamilton- Jacobi- Bellman (HJB) equation for Export is:

$$r\ V_e\ (Q) = \max_q\{\ U_e(Q) + V_e'\ q\ \} \quad (17)$$

Substituting $p_p = a - bq - \tau$ into (16) yields:

$$U_e(Q) = \{a - bq - \tau - (c_1 + c_2\ Q)\}\, q + (w_e - z)Q^2 \quad (18)$$

Let us define $F_e(Q) = U_e(Q) + V_e'\ q$:

$$F_e(Q) = \{\ a - bq - \tau - (c_1 \ + c_2\ Q)\}\ q + \ (w_e \ - z)Q^2 \ \ + V_e'\ q$$

The first order condition is:

$$\frac{\partial F_e}{\partial \mathrm{q}} = \{\ a - bq - \tau - (c_1 \ + c_2\ Q)\} - b + V_e' \ = 0 \qquad (19)$$

Assuming linear quadratic function for the value function of Export:

$$V_e(Q,t) = A_e Q^2 + B_e Q + C_e \qquad (20)$$

$$V_e'\ (Q) = 2A_e Q + B_e \qquad (21)$$

Substituting $q(Q) = \alpha Q + \beta$ and $V_e' \ = \ 2A_e Q + B_e$ into the first order condition (19),

$$\{\ a - b(\alpha Q + \beta) - \ \tau - \ (c_1 + c_2\ Q)\} - b + 2A_e Q + B_e = 0$$

$$(-b\alpha + 2A_e - c_2)Q + a - b\beta - \ \tau - c_1 - b + B_e = 0$$

and equating the coefficients, we obtain:

$$\alpha = \frac{1}{b}(2A_e - c_2) \qquad (22)$$

$$\beta = \frac{1}{b}(a - c_1 + \tau + b - B_e) \qquad (23)$$

The strategy of Export is described as:

$$q(Q) = \frac{1}{b}(2A_e - c_2)Q + \ \frac{1}{b}(a - c_1 + \tau + b - B_e) \qquad (24)$$

Substituting $q\ (Q\ ) \ = \alpha Q + \beta$ and $V_e' \ = \ 2A_e Q + B_e$ into $F_e(Q)$, and rearranging the coefficients of $F_e(Q)$:

$$F_e(Q) = Q^2\{\alpha\ (-b\alpha - c_2) + (w_e - z) + \ 2aA_e\} + \mathrm{Q}\{\beta(-b\alpha - c_2) + \alpha\left(a - \ \tau \ - \ c_1\right) + (2Ae\beta{+}\alpha Be) + \beta a {-}\ \tau \ - c1{+}Be\beta$$

By equating the coefficients of both sides of HJB equation with regard to Q^2, Q, and constant terms, we have:

$$rA_e = \ \ (-b\ \alpha^2 - c_2\ \alpha) + (w_e - z) + 2\alpha A_e \qquad (25)$$

$$rB_e = \beta\left(-b\alpha - c_2\right) + \alpha\left(a - \ \tau \ - \ c_1\right) + \ (2A_e\beta + \alpha B_e) \qquad (26)$$

$$rC_e = \ \beta\left(a - \ \tau \ - \ c_1\right) + B_e\beta \qquad (27)$$

$$A_e = \frac{1}{r-2\alpha}\{(-b\ \alpha^2 - c_2\ \alpha) + (w_e - z)\ \} \qquad (28)$$

$$B_e = \frac{1}{r-\alpha}\ \ \{\beta(-b\alpha - c_2) + \alpha\left(a - \ \tau \ - \ c_1\right) + \ 2A_e\beta\} \qquad (29)$$

$$C_e = \frac{1}{r}\{\beta\left(a - \ \tau \ - \ c_1\right) + B_e\beta\} \qquad (30)$$

2.4 Cooperation between Import and Export

This subsection turns to the case of cooperation between oil exporting country and oil importing country. Let us define the global utility as $U_g(Q) = U_i(Q) + U_e(Q)$ and from the equation (5) and (16), we obtain:

$$U_g(Q) = U_i(Q) + U_e(Q)$$

$$= (\tfrac{1}{2b} - b)q^2 + \{a - (c_1 + c_2\,Q)\}\,q + (w_i + w_e - z)\,Q^2 \qquad (31)$$

Note that from $q = \frac{1}{b}(a - p_p - \tau)$ (3), by choosing q, summation of $p_p + \tau$ is equals to $a - bq$. The Hamilton- Jacobi- Bellman (HJB) equation for cooperative planner is defined as:

$$r\,V_g\,(Q) = \max_q\{\,U_g(Q) + V_g'\,(Q)q\,\} \qquad (32)$$

where we assume linear quadratic form for the value function of the cooperative planner:

$$V_g(Q) = A_gQ^2 + B_gQ + C_g \qquad (33)$$

$$V_g'\,(Q) = 2A_gQ + B_g \qquad (34)$$

Let us define $F_g = U_g(Q) + V_g'\,q$:

$$F_g(Q) = \left(\tfrac{1}{2b} - b\right)q^2 + \{a - (c_1 + c_2\,Q)\}q + (w_i + w_e - z)Q^2 + V_g'\,(Q)q \qquad (35)$$

The first order condition of the cooperative planner is:

$$\frac{\partial F_g}{\partial \mathrm{q}} = 2\left(\tfrac{1}{2b} - b\right)q + \{a - (c_1 + c_2\,Q)\} + V_g'(Q) = 0 \qquad (36)$$

$$V_g'\,(Q) = -2\left(\tfrac{1}{2b} - b\right)q - \{a - (c_1 + c_2\,Q)\} \qquad (37)$$

Substituting V_g' of (27) in the equation of $F_g(Q)$, we obtain:

$$F_g(Q) = -\left(\tfrac{1}{2b} - b\right)q^2 + (w_i + w_e - z)Q^2 \qquad (38)$$

Inserting $q\,(Q) = \alpha_gQ + \beta_g$ into (31), and rearranging the coefficients of Q^2, Q and the constant term, we obtain:

$$r\left(A_gQ^2 + B_gQ + C_g\right) = -\left(\tfrac{1}{2b} - b\right)(\alpha_gQ + \beta_g)^2 + (w_i + w_e - z)Q^2$$

$$rA_g = -\left(\tfrac{1}{2b} - b\right)({\alpha_g}^2) + (w_i + w_e - z) \qquad (39)$$

$$rB_g = -2\left(\tfrac{1}{2b} - b\right)\alpha_g\beta_g \qquad (40)$$

$$rC_g = -\left(\tfrac{1}{2b} - b\right){\beta_g}^2 \qquad (41)$$

$$A_g = \tfrac{1}{r}\{-\left(\tfrac{1}{2b} - b\right)({\alpha_g}^2) + (w_i + w_e - z)\} \qquad (42)$$

$$B_g = -\tfrac{2}{r}\left(\tfrac{1}{2b} - b\right)\alpha_g\beta_g \qquad (43)$$

$$C_g = -\tfrac{1}{r}\left(\tfrac{1}{2b} - b\right){\beta_g}^2 \qquad (44)$$

3. IMPLICATION
3.1 Rate of extraction

In the previous section, we obtained the strategy of Export $q(Q){=}\alpha Q + \beta$ in an implicit form:

$$q(Q) = \frac{1}{b}(2A_e - c_2)Q + \frac{1}{b}(a - c_1 + \tau + b - B_e) \qquad (24)$$

Solving the following two equations (22) and (28) for α:

$$\alpha = \frac{1}{b}(2A_e - c_2) \qquad (22)$$

$$A_e = \frac{1}{r-2\alpha}\{(-b\,\alpha^2 - c_2\,\alpha) + (w_e - z)\} \qquad (28)$$

We obtain explicit form of α as follows:

$$\alpha = \frac{1}{br}\{2(w_e - z) + c_2 r\} \qquad (45)$$

The equations (24) and (45) imply that:

(a) The carbon tax imposed in Import increases oil extraction q at the rate of $\frac{\tau(1+\alpha)}{b}$.
(b) Extraction rate q increases as cumulative extraction Q increases if utility of consumption w_e is larger than disutility of climate change z in Export.
(c) The larger the increase rates of extraction cost c_2; the larger the increase rate of extraction.
(d) Even if disutility of climate change z is larger than utility of oil consumption w_e , there still be a possibility of positive increase of extraction rate when the increase rate of extraction cost c_2 is sufficiently large.
(e) The steeper the slope of demand curve; the larger the extraction increase rate α.
(f) The larger the price gap between alternative energy a and oil price c_1 at $q = 0$, the larger the oil extraction q is.

3.2 Oil price

Let us investigate the producer price of oil by inserting linear strategies of Import and Export $\tau(Q) = -2A_i Q - B_i$ and $q\,(Q) = \alpha Q + \beta$ to the consumer's demand equation.

$$p_p = a - bq - \tau = a - b(\alpha Q + \beta) + (2A_i Q + B_i)$$

$$= (2A_i - b\alpha)Q + a - b\beta + B_i \qquad (46)$$

From (46) increase rate of price is proportional to $2A_i - b\alpha$ = k and by inserting $A_i = \frac{1}{r+2\alpha}(\frac{1}{2b}\alpha^2 + w_i - z)$ and $\alpha = \frac{1}{br}\{2(w_e - z) + c_2 r\}$, we obtain:

$$k = 2A_i - b\alpha = \frac{2}{r+2\alpha}(\frac{1}{2b}\alpha^2 + w_i - z) - \frac{1}{r}\{2(w_e - z) + c_2 r\} \qquad (47)$$

Equation (47) implies that increase rate of oil price k is larger at the following conditions:

(a) The utility of oil consumption in Import w_i is large enough compared with disutility of climate change z.

(b) The disutility of climate change in Export z is large enough compared with utility of oil consumption in Export.

(c) Larger increase rate of extraction cost c_2.

(d) The slope of demand curve b is smaller.

3.3 Cumulative consumption of oil

At the terminal condition, $= \bar{Q}$, $\overline{p_p} = c_1 + c_2\bar{Q} = a$, we obtain from equation (24),

$$\bar{Q} = \frac{b\beta + B_i}{(2A_i - b\alpha)} = \frac{a - c_1}{c_2} \tag{48}$$

From (48), the amount of cumulative oil extraction is larger if a and c_2 are larger, c_1 is smaller. Therefore, it implies that in order to decrease total consumption of oil:

(a) Reduce backstop price of alternative energy a

(b) Reduce current exploration cost c_1

(c) Increase rate of extraction cost c_2 which assumed to be linear to Q

In the Stackelberg differential game setting with Import leadership, total carbon dioxide emission could be reduced by mitigating current oil extraction cost. However, mitigation of future extraction cost (e.g., unconventional oil and gas) does not lead to mitigation of total carbon dioxide emission.

3.4 Cooperation between Import and Export

Inserting $q(Q) = \alpha_g Q + \beta_g$ into (30), and rearranging the coefficients of Q and the constant term and compare them with equation (27), we obtain,

$$V_g'(Q) = 2A_gQ + B_g = -2\left(\frac{1}{2b} - b\right)(\alpha_g Q + \beta_g) - \{a - (c_1 + c_2 Q)\} \tag{49}$$

$$2A_g + 2\left(\frac{1}{2b} - b\right)\alpha_g - c_2 = 0 \tag{50}$$

$$B_g + 2\left(\frac{1}{2b} - b\right)\beta_g + (a - c_1) = 0 \tag{51}$$

Equating A_g and B_g in (35), (36) and (39), (40), we obtain:

$$\frac{1}{r}\left\{\left(\frac{1}{2b} - b\right)\left(\alpha_g{}^2\right) - (w_i + w_e - z)\right\} = \left(\frac{1}{2b} - b\right)\alpha_g - \frac{c_2}{2}$$

$$\frac{2}{r}\left(\frac{1}{2b}-b\right)\alpha_g\beta_g = 2\left(\frac{1}{2b}-b\right)\beta_g + (a-c_1)$$

In order to simplify above equations by substituting $\frac{1}{2b}-b=l$, $w_i+w_e-z=m$, we obtain:

$$l{\alpha_g}^2 - rl\alpha_g + \frac{rc_2}{2} - m = 0$$

$$\frac{2}{r}l\alpha_g\beta_g - 2l\beta_g - (a-c_1) = 0$$

$$\alpha_g = \frac{rl \pm \sqrt{(rl)^2 + 4l(\frac{rc_2}{2}-m)}}{2l} \quad (52)$$

$$\beta_g = \frac{(a-c_1)}{(\frac{2}{r}l\alpha_g - 2l)} \quad (53)$$

Explicit solutions (52) and (53) have the following implications for cooperative planner:

(a) The summation of utility of oil extraction and that of consumption $w_i + w_e$ is larger and disutility of climate change is smaller; the rate of extraction α_g is larger.

(b) The rate of cost increase $c_2$is larger; the rate of extraction α_g is larger.

(c) The cost gap between alternative energy and oil; $a-c_1$is larger, constant part of extraction rate β_g is larger.

(d) Carbon tax of Import does not have direct impact on extraction rate of Export in an explicit form

Thus, in a cooperative setting, Import and Export could cooperate in reducing the cost of oil extraction for both fixed part and increasing part and also the cost of alternative energy to mitigate growing rate of extraction.

4. CONCLUTION

The anthropogenic emissions of carbon dioxide are caused by the combustion of fossil oil. Major instruments of mitigation of carbon dioxide are focused on demand side management such as carbon tax or carbon credit. Sinn (2008) pointed out the importance of supply side approach and argued that some instruments for mitigation of carbon dioxide emission might increase emission ("Green Paradox"). However, there are not many literatures which studied impact of the demand side instruments on Export's incentive of oil production in a differential game setting.

We have examined strategic interaction between an oil importing country and an oil exporting country in a differential game setting. We employed the model of Stackelberg feedback equilibrium with leadership of Import considering time-consistency. This paper extends the previous differential game models in the literatures by two important features considering policy implication toward supply side incentive. Firstly we incorporate utility of oil consumption and disutility of climate change in value functions, both of which depends on cumulative oil consumption. Secondly, we incorporate cost structure of oil extraction and differentiate the cost of fixed part and increasing part.

In the differential game with Stackelberg leadership of importing country, we have shown that carbon tax in an oil importing country increases oil extraction rate in an oil exporting country. We investigated a cooperative case between the countries and found that carbon tax's effect on extraction rate is not straightforward. The results imply that future research should investigate carbon tax by taking care of incentive of oil extraction. We have also shown that the larger increase rate of extraction cost is, the larger the rate of oil extraction becomes, whereas, the larger increase rate of extraction results in less amount of cumulative extraction in both Stackelberg case and cooperative case. Therefore, we should design the trajectories of carbon dioxide emission and oil extraction in an integrated manner for climate policy design. We also have found that the balance of utility of oil consumption and disutility of climate change in respective country has a significant impact on the speed of extraction and consumption of oil.

The results of this paper imply an importance of cost structure of oil and alternative energy for climate policy design and security supply of oil as key parameters. Therefore, impact of emerging unconventional oil and gas will be future study agenda. It also suggests that technical cooperation between oil importing countries and oil exporting countries to manage the cost structure of oil is a critical factor for designing policies in climate change and energy security.

The scope of our results in this paper is limited by specification of the game in order to derive explicit solutions. However, the presented model and its analysis have implications on policy discussion on climate change and security supply of oil. Therefore it is important to extend researches toward policy design of climate change incorporating the incentives of oil producing countries.

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