Hitotsubashi Journal of Economics 59 (2018), pp.25-43.

THE TIMING OF ENVIRONMENTAL TAX POLICY WITH A CONSUMER-FRIENDLY FIRM*

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Received March 2018; Accepted March 2018

Abstract

This study considers a Cournot duopoly model with a consumer-friendly firm and analyzes the interplay between the strategic choice of abatement technology and the timing of government's commitment to the environmental tax policy. We show that the optimal emission tax under committed policy regime is always higher than that under non-committed one, but both taxes can be higher than marginal environmental damage when the consumer-friendliness is high enough. We also show that the emergence of a consumer-friendly firm might yield better outcomes to both welfare and environmental quality without the commitment to the environmental policy.

Keywords: abatement technology, commitment, consumer-friendly firm, emission tax, environmental policy
JEL Classification Codes: L13, L31, Q58

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* We thank an anonymous referee for constructive comments. This work has been supported by the Ministry of Education of the Republic of Korea, the National Research Foundation of Korea (NRF-2017S1A5B8059731) and CONACYT, Mexico.
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I. *Introduction*

Recently, a large number of companies participated in fair trade or greenhouse gas reduction programs and issued various statements on corporate social responsibility (CSR) and outlined activities in their annual reports.[1] Due to the current expansion of CSR, many industries are characterized by the co-existence of for-profit firms and not-for-profit firms. Thus, the heterogeneity of objectives among the firms emerges as an essential research topic in the literature.[2]

Numerous theoretical studies have formulated models for analyzing the CSR activities in different competition models.[3] In the fields of public economics and industrial organization, many studies considered an oligopoly model where profit-maximizing firms compete with their rival firms that adopt CSR activities. In particular, as one way of adopting CSR initiatives, they utilized consumer surplus as a proxy of CSR concern and define the objective of the firm as a combination of consumers surplus and its profits. Then, the firms put a higher weight on output in an oligopoly, which induces rivals to reduce their output and thus profits can be higher for a firm which adopts CSR activities.[4] Thus, the firm may strategically use CSR initiative as a commitment to expand the outputs and thus the firm that adopts CSR obtains higher profits than its profit-seeking competitors and induces a higher level of social welfare. However, these results put aside the environmental policy, which is becoming an essential part of contemporary economies. As pointed out Lambertini and Tampieri (2015) and Garcia et al. (2018), in the presence of an environmental problem, firms concern on CSR (and thus committing a higher output) might be neither profitable to the firms nor desirable to the society.

In the process of policy-making, on the other hand, the ability of a government to commit credibly to an environmental policy has significant implications to support the superior welfare properties associated with a committed policy. Due to the political reason, however, if the regulator can not commit credibly to the stringency of the policy instrument, firms have strategic incentives because the regulator has an ex-post possibility to ratchet up regulation.[5] Petrakis and Xepapadeas (1999), Poyago-Theotoky and Teerasuwannajak (2002) and Moner-Colonques and Rubio (2015) examined environmental taxation under the time inconsistency problem when the regulator is not able to commit credibly and showed an interesting result that firms undertake increased abatement activities generating less pollution, which might result in higher welfare. However, they concentrated on the symmetric case of homogeneous objectives where both firms only maximize their profits under environmental policies. Thus, a symmetric equilibrium can produce the same incentive to ratchet down regulation and increase profits and

[1] See CSR trend report by PricewaterhouseCoopers (2010) and KPMG (2013, 2015).

[2] For example, Chirco et al. (2013), Matsumura and Ogawa (2014), Flores and Garcia (2016) and Cho and Lee (2017) showed that behavioral heterogeneity may produce different market structure.

[3] In the CSR literature, see Goering (2012, 2014), Kopel and Brand (2012), Brand and Grothe (2013, 2015), Nakamura (2014), Chang et al. (2014), Kopel (2015) and Matsumura and Ogawa (2014, 2017) among others.

[4] The approach that CSR concerns account for consumer surplus is very closely related to the literature on strategic delegation and sales targets for managers in oligopolies, as suggested by Fershtman and Judd (1987) and Vickers (1985).

[5] See, for example, Gersbach and Glazer (1999), Requate and Unold (2003) and D'Amato and Dijkstra (2015) for a commitment issue regarding environmental regulation.

welfare under efficient abatement technology. In the present paper, we complement and elucidate these works by examining the role of CSR that can play in designing of environmental policy under asymmetric equilibrium.

In this paper, we consider a quantity-setting Cournot duopoly model with heterogeneous objectives between firms where a consumer-friendly firm competes with a for-profit firm emitting pollutants in the presence of emission tax.[6] We then analyze the interplay between the strategic choice of abatement technology and the timing of government's commitment to the environmental policy. In specific, we consider the ability of the environmental regulator to commit credibly or not to an emission tax, and examine the properties of either committed or non-committed regime regarding environmental policy. In the former case of the *committed policy regime*, the regulator sets the emission tax then the firms, taking the tax rate as given, choose abatement investment. In the latter case of the *non-committed policy regime*, firms first select their abatement levels and then the regulator sets the emission tax. Thus, under the non-committed policy regime, when an emission tax is chosen firms would expect the regulator to change it after they have determined their investment in abatement. We investigate this time-inconsistency problem in deciding environmental policy in the presence of a consumer-friendly firm.

The main findings we obtain are as follows: Regarding positive implications on emission taxes, we show that the tax rate under the committed policy regime is always higher than that under the non-committed one, but both emission taxes can be higher than marginal environmental damage when the consumer-friendliness is high enough. It represents that the strategic incentive of innovation will ratchet down the regulator's ex-post possibility to decide tax rate, which is dependent of the strategic relation between the firms. In particular, as the concern on consumer surplus rises, a consumer-friendly firm produces more outputs aggressively, which increases total outputs and total emissions even under higher abatement levels. Thus, irrespective of policy regimes, the optimal emission tax will be higher than Pigouvian level. This sharply contrasts to the previous result in the private market where firms have homogeneous payoffs under environmental taxation. For example, Shaffer (1995) and Lee (1999) showed that the optimal emission tax should be lower than marginal environmental damage under oligopolistic competition.[7]

Regarding normative implications on the two policy regimes, we also show that the non-committed policy regime can induce the firms to decide not only more outputs and higher profits but also more abatement and less emissions than under the commitment when the consumer-friendliness is high and the efficiency of abatement technology is not so high. Therefore, a consumer-friendly firm under the non-committed policy regime might yield better outcomes to the welfare and environmental quality as well. It implies that the heterogeneity of objectives between the firms are significant in designing of environmental policies.[8]

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[6] Similar market configuration can be found in the literature on mixed oligopolies where the objectives between public and private firms differ. Recent works on mixed markets with environmental tax policies can be found in Wang and Wang (2009), Pal and Saha (2014, 2015), Xu et al. (2016), Kim et al. (2018) and Lee and Xu (2018) among others.

[7] In the literature on environmental taxation, the rationale for a higher or lower optimal tax level depends on the relative effects of distortions, such as market powers between the related markets with abatement technologies, excessive or insufficient entry, and externality. See, for example, Canton et al. (2005), Requate (2007) and Lee and Park (2011) among others.

The remainder of this paper is organized as follows. In section 2, we formulate a Cournot duopoly model with a consumer-friendly firm having abatement technology. We analyze a committed and a non-committed policy regimes, respectively, in section 3 and 4. In section 5, we compare the results and provide main findings. We conclude the paper in section 6.

II. *The Model*

We consider a quantity-setting Cournot duopoly model.[9] One of the firms is a consumer-friendly (CF) firm (hereafter referred to as firm 0) that cares for not only its profits but consumers surplus. The other is a for-profit (FP) firm (hereafter referred to as firm 1) that maximizes only its profits. Firms sell homogeneous output, $q_0>0$ and $q_1>0$, respectively, at the market clearing price $p(Q)=1-Q$ where $Q=q_0+q_1$. We assume that both firms have identical technologies and the production cost function takes a quadratic form, $c(q_i)=\frac{1}{2}q_i^2$, $i\in\{0, 1\}$.

Production leads to pollution, $e_i>0$, but each firm can reduce pollution by undertaking abatement activities. Suppose that firm i chooses pollution abatement level $a_i>0$. Then, the emission level can be reduced to $e_i=q_i-a_i$ by investing an amount of $\left(\frac{k}{2}\right)a_i^2$ in abatement, which is characterized by decreasing returns.[10] Note that a lower value of k implies higher efficiency of the abatement technology. To guarantee an interior solution in the analysis, we assume the followings:

$$k>\underline{k}(\theta)=\frac{1}{4(2-\theta)}\left(\sqrt{400-544\theta+248\theta^2-8\theta^3+\theta^4}-(20-20\theta+\theta^2)\right). \qquad (1)$$

Note that $\underline{k}(0)=0$ and $\underline{k}(\theta)$ increases on θ.

The extent of environmental damage due to pollution by the industry is given by $ED=\frac{\left(\sum_i e_i\right)^2}{2}$, where the marginal environmental damage is $MED=\sum_i e_i$. The government imposes an environmental tax on the emission level, for which the uniform tax rate is t. The total tax revenue is $T=t\sum_i e_i$.

The profit of CF firm is given by $\pi_0=p\cdot q_0-\frac{1}{2}q_0^2-t\cdot e_0-\frac{k}{2}a_0^2$. We assume that the CF firm maximizes profits plus a fraction of consumer surplus (CS). Thus, the payoff that CF firm

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[8] In the literature on CSR, different approaches on the objectives of a consumer-friendly firm emitting emissions have been proposed. For example, Liu et al. (2015), Lambertini and Tampieri (2015) and Garcia et al. (2018) considered net consumer surplus or different weights on consumer surplus and environmental damages in the objectives of the firms with CSR-initiatives, while Lee and Park (2018) and Hirose et al. (2017) emphasized environmental damages only. In Appendix C, we examine the case in Liu et al. (2015) where the consumer-friendly firm cares for net consumer surplus and show that most findings in the analysis hold.

[9] Our model could be extended to the oligopoly model without further insights gained.

[10] The particular choice of the end-of-pipe technology in the specification of the pollution generation process is made for the sake of simplifying the analysis where there is no strategic effect under the committed regime.

maximizes is as follows:

$$V_0=\pi_0+\theta CS \tag{2}$$

where $CS=\frac{Q^2}{2}$. The parameter $\theta\in(0, 1)$ measures the degree of concern on consumer surplus that the CF firm has, which is exogenously given.

The FP firm seeks only for profit maximization:

$$\pi_1=p\cdot q_1-\frac{1}{2}q_1^2-t\cdot e_1-\frac{k}{2}a_1^2 \tag{3}$$

The social welfare is the sum of consumer surplus, CS, the profits of both firms, $\pi_0+\pi_1$, and tax revenue, T, minus environmental damage, ED:

$$W=CS+\pi_0+\pi_1+T-ED \tag{4}$$

We shall consider two alternative policy regimes, each featuring a three-stage game between a welfare-maximizing regulator and firms, to examine the properties of either a committed or a non-committed policy regime regarding environmental policy. In the former case of the *committed policy regime*, the regulator sets the emission tax then the firms, taking the tax rate as given, choose abatement investment simultaneously and independently. In the latter case of the *non-committed policy regime*, firms first select their abatement levels and then the regulator sets the emission tax. Finally, in both regimes the firms select outputs in the third stage.

III. *The Committed Policy Regime*

In the third stage firms 0 and 1 choose their outputs to maximize (2) and (3), respectively, given the emission tax rate, t. Using the first-order conditions we get the following equilibrium output level of each firm and total outputs:

$$q_0=\frac{(1-t)(2+\theta)}{2(4-\theta)},\ q_1=\frac{(1-t)(2-\theta)}{2(4-\theta)},\ Q=\frac{2(1-t)}{4-\theta} \tag{5}$$

Note that each firm's output decreases in the emission tax. Also if the concern on consumer surplus rises, the CF firm is more aggressive and thus increases its output while the FP firm decreases the output. However, the total outputs increases.

In the second stage, firms choose abatement efforts to maximize their payoffs. Firm 0 chooses a_0 that maximizes (2) while firm 1 chooses a_1 that maximizes (3). Solving these problems gives the equilibrium abatement level as a function of the tax:

$$a_i=\frac{t}{k},\quad i\in\{0, 1\} \tag{6}$$

that defines a positive relationship between abatement and the emission tax. Note that there is no strategic interaction between the firms.

In the first stage the government sets the emission tax that maximizes social welfare in (4).

Solving the first-order condition yields the optimal emission tax, which is given by[11]

$$t^c = \frac{k(8(4-\theta)+k(2+\theta)^2)}{D} \tag{7}$$

where $D = k^2(20+\theta^2)+4k(32-12\theta+\theta^2)+8(4-\theta)^2 > 0$. We employ superscript c to denote the equilibrium under the committed policy regime. From (7) the equilibrium output, abatement and emission levels are obtained:

$$q_0^c = \frac{2(2+k)(4-\theta+k)(2+\theta)}{D} \tag{8}$$

$$q_1^c = \frac{2(2+k)(4-\theta+k)(2-\theta)}{D}$$

$$a_0^c = a_1^c = \frac{8(4-\theta)+k(2+\theta)^2}{D}$$

$$e_0^c = \frac{4k(5+k)+2(8+2k+k^2)\theta-(4+3k)\theta^2}{D}$$

$$e_1^c = \frac{4k(5+k)-2(8+10k+k^2)\theta+(4+k)\theta^2}{D}$$

In equilibrium under the committed policy regime, the CF firm's output is larger than that of the FP firm's, but both firms make the same abatement effort; therefore the CF firm's emission level is also larger than its rival's. Note that $\partial q_0^c/\partial\theta > 0$, $\partial q_1^c/\partial\theta < 0$ and $\partial a_i^c/\partial\theta > 0$, $i \in \{0, 1\}$ for any $\theta \epsilon (0, 1)$.

Finally, we have the resulting profits of the firms, environmental damage and social welfare:

$$\pi_0^c = \frac{4(2+k)^2(4+k-\theta)^2(2+\theta)(6-5\theta)+k(8(4-\theta)+k(2+\theta)^2)^2}{2D^2}$$

$$\pi_1^c = \frac{12(2+k)^2(4+k-\theta)^2(2-\theta)^2+k(8(4-\theta)+k(2+\theta)^2)^2}{2D^2}$$

$$MED^c = \frac{2k(20+4k-8\theta-\theta^2)}{D} \tag{9}$$

$$ED^c = \frac{2k^2(20+4k-8\theta-\theta^2)^2}{D^2}$$

[11] Solving this problem gives the following first order condition: $-\frac{dED}{dt} = -(1-Q(t))\frac{dQ}{dt} + \sum_{i=0}^{1} q_i(t)\frac{dq_i}{dt} + k\sum_{i=0}^{1} a_i(t)\frac{da_i}{dt}$ where the left-hand side measures the marginal benefit of taxation that is given by the reduction in environmental damages associated to an increase in the emission tax rate and the right-hand side the marginal cost of taxation that has three components: the decrease in consumer surplus coming from the fall in output market, the decrease in the output of each firm, the raise in investment costs all caused by an increase in the emission tax rate.

$$W^c=\frac{(2+k)(4k+(2-\theta)(10+\theta))}{D}$$

Proposition 1. *Under the committed policy regime,* $\pi_1^c<\pi_0^c$ *for any* $\theta\epsilon(0,1)$.

It states that in equilibrium under the committed policy regime, the profit of CF firm is always larger than that of FP firm because the CF firm is more aggressive in production, which induces less production of FP firm.[12]

Proposition 2. *Under the committed policy regime:*[13]

1. $t^c \lesseqgtr MED^c$ *if* $\theta \lesseqgtr 2(-1+\sqrt{2})\approx 0.828$;
2. $\frac{\partial t^c}{\partial\theta}>0$ *and* $\frac{\partial(MED^c-t^c)}{\partial\theta}<0$ *for any* $\theta\epsilon(0,1)$;
3. $\frac{\partial ED^c}{\partial\theta}>0$ *and* $\frac{\partial W^c}{\partial\theta}>0$ *for any* $0<\theta<\frac{1}{2}(9-\sqrt{65})\approx 0.468$ *if* $\underline{k}<k<\frac{4-8\theta}{\theta}$.

Proposition 2.1 states that as like the results in the previous literature on the oligopoly model with emission tax, with a small degree of consumer-friendliness the emission tax under the committed regime is lower than the marginal environmental damage.[14] But the tax rate increases as θ increases and thus, interestingly, the opposite result occurs with a high value of θ. Therefore, as the concern on consumer surplus rises, a consumer-friendly firm produces more outputs aggressively, which increases total outputs and total emissions even under higher abatement levels. Thus, the optimal emission tax will be higher than marginal environmental damage. Finally, Proposition 2.3 states that both welfare and environmental damage are simultaneously decreasing or increasing depending on the values of θ and k. This result represents a typical trade off between welfare and environmental damage in the literature.

IV. *The Non-committed Policy Regime*

The last stage in production is the same as in the previous committed policy regime. In the second stage, the regulator chooses the welfare maximizing emission tax taking as given the firms' abatement levels. The first order condition of this problem yields

$$t=\frac{(2+\theta)^2-4(4-\theta)(a_0+a_1)}{20+\theta^2} \tag{10}$$

This expression defines an inverse relationship between firms' abatement investments and the

[12] For more discussion on this point, see Lambertini and Tampieri (2015) and Garcia et al. (2018).

[13] The proofs are provided in Appendix B with the comparable figures, instead of formal mathematics, if it is not straightforward.

[14] For example, Shaffer (1995) and Lee (1999) examined the blockaded-entry and free-entry models, respectively, and showed that the optimal emission tax might fall short of marginal environmental damage. Further analysis on the rationale for a higher or lower optimal tax level, see Canton et al. (2005), Lee and Park (2011) and Requate (2007) among others.

emission tax, that is, the regulator decreases the emission tax rate in response to an increase in the firms' abatement levels. Thus, firms can strategically use its choice of abatement to influence taxation: by increasing investment in emission-reducing activities, the firms can expect a lower emission tax. Also as the concern on consumer surplus increases, so does the emission tax.

In the first stage, firms choose their abatement efforts taking into account how the regulator is going to respond. Firm 0 chooses a_0 that maximizes (2) while firm 1 chooses a_1 that maximizes (3). Solving these problems gives the following reaction functions:

$$a_0=\frac{128+128\theta+4\theta^2+4\theta^3+\theta^4-4(68-32\theta+9\theta^2-\theta^3)a_1}{592-208\theta+52\theta^2-8\theta^3+k(20+\theta^2)^2}$$
$$a_1=\frac{128+32\theta+36\theta^2+4\theta^3+\theta^4-4(68-8\theta+\theta^2-\theta^3)a_0}{592-112\theta+20\theta^2-8\theta^3+k(20+\theta^2)^2} \quad (11)$$

Since the slope of the reaction functions is negative, abatement efforts are strategic substitutes. This is in contrast to the commitment case where $\partial a_i/\partial a_j=0$. Solving the reaction functions we derive the following equilibrium abatement efforts:

$$a_0^{nc}=\frac{4(512+864\theta-272\theta^2+36\theta^3-8\theta^4-\theta^5)+k(20+\theta^2)(128+128\theta+4\theta^2+4\theta^3+\theta^4)}{N}$$
$$a_1^{nc}=\frac{4(512-480\theta+272\theta^2-44\theta^3+8\theta^4-\theta^5)+k(20+\theta^2)(128+32\theta+36\theta^2+4\theta^3+\theta^4)}{N} \quad (12)$$

where $N=(4(4-\theta)+k(20+\theta^2))\cdot H>H=864-240\theta+56\theta^2-12\theta^3+k(20+\theta^2)^2>0$. We also employ superscript nc to denote the equilibrium under the non-committed policy regime.

Proposition 3. *Under the non-committed policy regime, $a_0^{nc}>a_1^{nc}$ for any $\theta\epsilon(0, 1)$.*

It states that CF firm is more aggressive in investing abatement technology, which induces a larger amount of total abatement under the non-committed policy regime. Note that $\partial a_0^{nc}/\partial\theta>0$ and $\partial(a_0^{nc}+a_1^{nc})/\partial\theta>0$ for any $\theta\epsilon(0, 1)$.

The optimal emission tax is:

$$t^{nc}=\frac{k(2+\theta)^2(20+\theta^2)-4(8-12\theta-2\theta^2+\theta^3)}{H} \quad (13)$$

From (5) and (13) the equilibrium output and emission levels are obtained:

$$q_0^{nc}=\frac{2(2+\theta)(k(20+\theta^2)+2(28-2\theta+\theta^2))}{H}$$
$$q_1^{nc}=\frac{2(2-\theta)(k(20+\theta^2)+2(28-2\theta+\theta^2))}{H}$$
$$e_0^{nc}=\frac{2k^2(20+\theta^2)^2(2+\theta)+k(20+\theta^2)(160-16\theta-12\theta^2-\theta^4)+4(384-704\theta+176\theta^2-20\theta^3+4\theta^4+\theta^5)}{N} \quad (14)$$
$$e_1^{nc}=\frac{2k^2(2-\theta)(20+\theta^2)^2+k(20+\theta^2)(160-208\theta-12\theta^2-8\theta^3-\theta^4)+4(384-256\theta-80\theta^2+12\theta^3-4\theta^4+\theta^5)}{N}$$

In equilibrium under the non-committed policy regime, the CF firm's output and abatement levels are larger than those of the FP firm. Thus, the emissions generated by the firms depend on θ and k.

Proposition 4. *Under the non-committed policy regime,* $e_0^{nc} < e_1^{nc}$ *for any* $0 < \theta < \theta_e \approx 0.33$ *if* $\underline{k} < k < k_e$ *where* $k_e(\theta)$ *satisfies that* $e_0^{nc}(k_e;\, \theta) = e_1^{nc}(k_e;\, \theta)$.

It states that the emissions generated by the CF firm can be less than those generated by the FP firm if its consumer-friendliness is low and the efficiency of abatement technology is relatively high. Note that $\partial q_0^{nc}/\partial\theta > 0$ and $\partial q_1^{nc}/\partial\theta < 0$ for any $\theta \epsilon (0, 1)$.

Finally, we have the resulting profits of the firms, environmental damage and social welfare:[15]

$$\begin{aligned}
\pi_0^{nc} &= \frac{\rho_4(\theta)k^4 + \rho_3(\theta)k^3 + \rho_2(\theta)k^2 + \rho_1(\theta)k + \rho_0(\theta)}{2N^2}, \\
\pi_1^{nc} &= \frac{\lambda_4(\theta)k^4 + \lambda_3(\theta)k^3 + \lambda_2(\theta)k^2 + \lambda_1(\theta)k + \lambda_0(\theta)}{2N^2}, \\
MED^{nc} &= \frac{2(96 - 96\theta - 12\theta^2 - 4\theta^3 - \theta^4 + 4k(20 + \theta^2))}{H}, \\
ED^{nc} &= \frac{2(96 - 96\theta - 12\theta^2 - 4\theta^3 - \theta^4 + 4k(20 + \theta^2))^2}{H^2}, \\
W^{nc} &= \frac{\sigma_4(\theta)k^4 + \sigma_3(\theta)k^3 + \sigma_2(\theta)k^2 + \sigma_1(\theta)k + \sigma_0(\theta)}{N^2}
\end{aligned} \qquad (15)$$

Proposition 5. *Under the non-committed policy regime,* $\pi_1^{nc} < \pi_0^{nc}$ *if* $0 < \theta < \theta_{\pi 1s} \approx 0.9428$.

It states that in equilibrium under the non-committed policy regime, the profit of CF firm can be larger than that of FP firm if the consumer-friendliness is not so high. It implies that concerning a certain portion of consumer surplus is beneficial to a CF firm irrespective of the timing of the commitment to the environmental policy.

Proposition 6. *Under the non-committed policy regime:*

1. $t^{nc} \lessgtr MED^{nc}$ *if* $\theta \lessgtr 2(-1+\sqrt{2}) \approx .828$;
2. $\dfrac{\partial t^{nc}}{\partial \theta} > 0$ *and* $\dfrac{\partial (MED^{nc} - t^{nc})}{\partial \theta} < 0$ *for any* $\theta \in (0, 1)$;
3. $\dfrac{\partial MED^{nc}}{\partial \theta} < 0$ *and* $\dfrac{\partial ED^{nc}}{\partial \theta} < 0$ *for any* $\theta \in (0, 1)$;
4. $\dfrac{\partial W^{nc}}{\partial \theta} > 0$ *for any* $0 < \theta < \theta_{W_{nc}} \approx 0.489$ *if* $\underline{k} < k < k_{W_{nc}}$ *where* $k_{W_{nc}}$ *satisfies that* $\dfrac{\partial W^{nc}}{\partial \theta} = 0$.

[15] For the sake of expositional convenience, we provide $\rho_i(\theta)$, $\lambda_i(\theta)$ and $\sigma_i(\theta)$ in Appendix A.

Propositions 6.1 states that with a small degree of consumer-friendliness the emission tax under the non-committed policy regime is also lower than the marginal environmental damage. But the tax rate increases as θ increases and thus the opposite occurs with a very high value of θ. This result is the same with that under the committed policy regime. However, Propositions 6.3 and 6.4 state that it is possible that welfare is increasing and environmental damage is decreasing with small values of θ and k. This result sharply contrast to the result under the committed policy regime where a trade off between welfare and environmental damage exists.

V. *Comparing Policy Regimes*

In this section we provide comparisons between the committed and non-committed policy regimes and summarize our findings in a number of propositions.

Proposition 7. $t^{nc} < t^{c}$ *for any* $\theta \in (0, 1)$.

The committed emission tax is larger than the non-committed one. The intuition is as follows: Under the non-committed policy regime, due to the time-inconsistency problem each firm has a strategic incentive to increase abatement in order to induce the regulator to impose a lower emission tax subsequently. It represents that the strategic incentive of innovation will ratchet down the regulator's ex-post possibility to decide tax rate, which is dependent of the strategic relation between the firms. This aspect is absent when the regulator pre-commit to an emission tax.[16]

Proposition 8.

1. $q_0^{nc} > q_0^c$, $q_1^{nc} > q_1^c$ *and* $Q^{nc} > Q^c$ *for any* $\theta \in (0, 1)$
2. $a_0^{nc} > a_0^c$, *for any* $\theta \in (0, 1)$ *if* $k > max\,[\underline{k}, k_{a_0}]$ *where* k_{a_0} *satisfies that* $a_0^c(k_{a_0}; \theta) = a_0^{nc}(k_{a_0}; \theta)$.
3. $a_1^{nc} > a_1^c$ *for any* $\theta \in (0, 1)$ *if* $k > k_{a_1}$ *where* k_{a_1} *satisfies that* $a_1^c(k_{a_1}; \theta) = a_1^{nc}(k_{a_1}; \theta)$.
4. $a_0^c + a_1^c < a_0^{nc} + a_1^{nc}$ *for any* $\theta \in (0, 1)$ *if* $k > max\,[\underline{k}, k_{aa}]$ *where* k_{aa} *satisfies that* $a_0^c(k_{aa}; \theta) + a_1^c(k_{aa}; \theta) = a_0^{nc}(k_{aa}; \theta) + a_1^{nc}(k_{aa}; \theta)$.

It states that compared to the committed policy regime, both firms increase not only outputs but abatement investments under the non-commitment policy regime when the efficiency of abatement technology is relatively low.

Proposition 9.

1. $\pi_0^c < \pi_0^{nc}$ *for any* $0 < \theta < \theta_{\pi_0} \approx 0.7713$ *if* $k > max\,[\underline{k}, k_{\pi_0}]$ *where* k_{π_0} *satisfies that* $\pi_0^c(k_{\pi_0}; \theta) = \pi_0^{nc}(k_{\pi_0}; \theta)$;
2. $\pi_1^c < \pi_1^{nc}$ *for any* $\theta \in (0, 1)$ *if* $k > max\,[\underline{k}, k_{\pi_1}]$ *where* k_{π_1} *satisfies that* $\pi_1^c(k_{\pi_1}; \theta) = \pi_1^{nc}(k_{\pi_1}; \theta)$.

It implies that both firms can earn higher profits under the non-committed policy regime when the efficiency of abatement technology is relatively low.

[16] This finding is also pointed out by Poyago-Theotoky and Teerasuwannajak (2002) and Moner-Colonques and Rubio (2015) in the context of non-committed environmental policy regime, but they did not consider the role of consumer-friendly firm.

Proposition 10.

1. $ED^c > ED^{nc}$ *for any* $\theta_{ED} \approx 0.4482 < \theta < 1$ *if* $k > max\,[\underline{k}, k_{ED}]$ *where* k_{ED} *satisfies that* $e_0^c(k_{ED};\, \theta) + e_1^c(k_{ED};\, \theta) = e_0^{nc}(k_{ED};\, \theta) + e_1^{nc}(k_{ED};\, \theta)$*;*
2. $W^c < W^{nc}$ *for any* $0 < \theta \leq \theta_W \approx 0.568$ *if* $k > k_W$ *where* k_W *satisfies that* $W^c(k_W;\, \theta) = W^{nc}(k_W;\, \theta)$.

Therefore, with large θ and high k the total emissions and thus environmental damage under the non-committed policy regime are smaller than the commitment one. Furthermore, with small θ and high k the welfare under the non-committed policy regime is larger than the commitment one. We can plot Figure 1a and 1b, and show the comparisons of environmental damage and welfare between the two different policy regimes, respectively. We can also plot Figure 2 and show that (i) the non-committed policy regime is better than the committed one, i.e., $ED^c > ED^{nc}$ and $W^c < W^{nc}$ if θ is intermediate and k is large while (ii) the committed policy regime is better than the non-committed one, i.e., $ED^c < ED^{nc}$ and $W^c > W^{nc}$ if both θ and k are small.

Figure 1. ED and Welfare Comparisons

(a) ED Comparison (b) Welfare Comparison

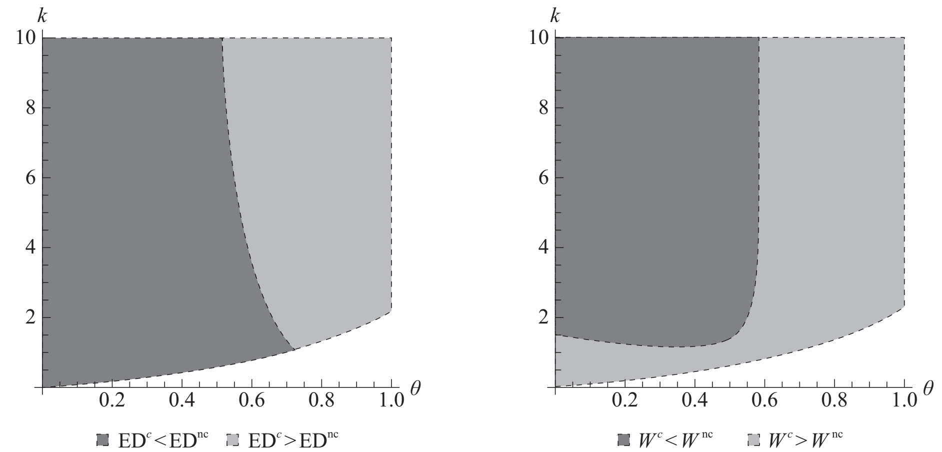
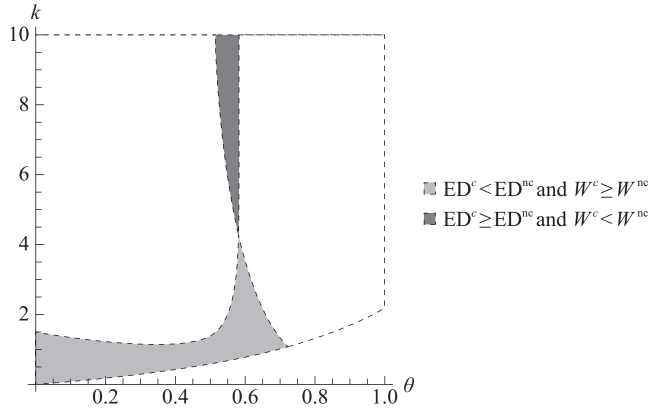


FIGURE 2. COMMITMENT VS. NON-COMMITMENT



VI. *Conclusion*

We have considered CSR initiatives of the firms and examined the timing of government's commitment to the environmental tax policy. We have emphasized the heterogeneity of objectives and its impact on the time inconsistency problem in which firms' strategic decisions on production and abatement activities might result in different welfare consequences. We have shown that the optimal emission tax under the committed policy regime is always higher than that under the non-committed one, but both taxes can be higher than marginal environmental damage when the consumer-friendliness is high enough. We also have shown that under the non-committed policy the firms decide not only more outputs and higher profits but also more abatement and less emissions when the consumer-friendliness is high and the efficiency of abatement technology is not so high. Therefore, the emergence of a consumer-friendly firm might yield better outcomes to the welfare and environmental quality without the commitment to the environmental policy under certain conditions. These results show that CSR initiatives can play a significant role in the design and implementation of environmental policy. The importance of CSR needs to be further examined in some alternative settings under different market structures to check the robustness of the results obtained in this paper. This has to be left for future research.

APPENDIX

Appendix A. The Values of $\rho_i(\theta)$, $\lambda_i(\theta)$ *and* $\sigma_i(\theta)$

$$\rho_0(\theta) \equiv 36438016 - 37486592\theta + 7356416\theta^2 + 26705920\theta^3 - 25436160\theta^4 + 9400320\theta^5 - 1884160\theta^6 + 256000\theta^7 - 15360\theta^8 - 128\theta^9$$

$\rho_1(\theta)\equiv16(7479296-59228816\theta-239616\theta^2+8212480\theta^3-510336\theta^4+1573120\theta^5-35440\theta^6+5856\theta^7-512\theta^8+48\theta^9+5\theta^{10})$

$\rho_2(\theta)\equiv16(20+\theta^2)(416512-2352640\theta-670080\theta^2+368320\theta^3-18800\theta^4+3568\theta^5-788\theta^6+38\theta^7-8\theta^8-\theta^9)$

$\rho_3(\theta)\equiv(20+\theta^2)^2(142336-532480\theta-318720\theta^2+84480\theta^3-3056\theta^4+608\theta^5-16\theta^6+8\theta^7+\theta^8)$

$\rho_4(\theta)\equiv4(20+\theta^2)^4(2+\theta)(6-5\theta)$

$\lambda_0(\theta)\equiv128(4-\theta)(71168-948480\theta+499200\theta^2-155200\theta^3+4560\theta^4-928\theta^5+120\theta^6-16\theta^7+\theta^8)$

$\lambda_1(\theta)\equiv16(7479296-100147200\theta+57405440\theta^2-19394560\theta^3+6186240\theta^4-1442560\theta^5+254880\theta^6-4576\theta^7+480\theta^8-48\theta^9+5\theta^{10})$

$\lambda_2(\theta)\equiv16(20+\theta^2)(416512-4651520\theta+2486400\theta^2-626240\theta^3+204960\theta^4-3312\theta^5+476\theta^6-82\theta^7-\theta^9)$

$\lambda_3(\theta)\equiv(20+\theta^2)^2(142336-1361920\theta+674560\theta^2-97280\theta^3+4880\theta^4-32\theta^5+112\theta^6+8\theta^7+\theta^8)$

$\lambda_4(\theta)\equiv12(2-\theta)^2(20+\theta^2)^4$

$\sigma_0(\theta)\equiv32(4-\theta)^2(109056-38400\theta+4352\theta^2-5760\theta^3-656\theta^4-352\theta^5-48\theta^6-8\theta^7-\theta^8)$

$\sigma_1(\theta)\equiv16(11329536-70881280\theta+17346560\theta^2-6686720\theta^3+442880\theta^4-193920\theta^5+2352\theta^6+48\theta^7+184\theta^8+36\theta^9+3\theta^{10}+\theta^{11})$

$\sigma_2(\theta)\equiv2(20+\theta^2)(4990976-20541440\theta+4382720\theta^2-2078720\theta^3-133760\theta^4-137600\theta^5-1328\theta^6-480\theta^7-52\theta^8-4\theta^9-\theta^{10})$

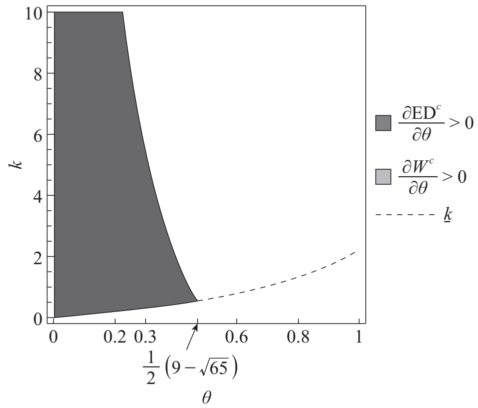
$\sigma_3(\theta)\equiv(20+\theta^2)^2(214016-460800\theta+156160\theta^2-52480\theta^3-336\theta^4-384\theta^5-40\theta^6-8\theta^7-\theta^8)$

$\sigma_4(\theta)\equiv4(20+\theta^2)^5$

Appendix B. Proofs

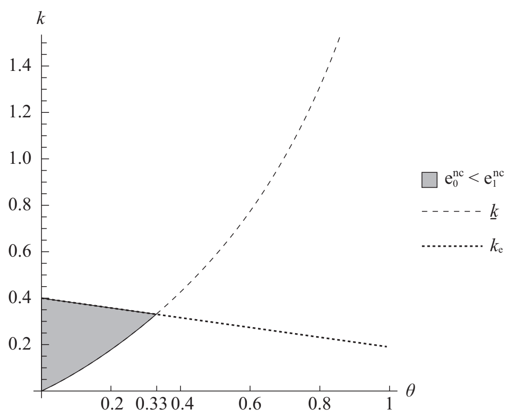
B.1 Proposition 2.3

FIGURE B.1. THE REGIONS OF $\frac{\partial ED^c}{\partial\theta}>0$ AND $\frac{\partial W^c}{\partial\theta}>0$



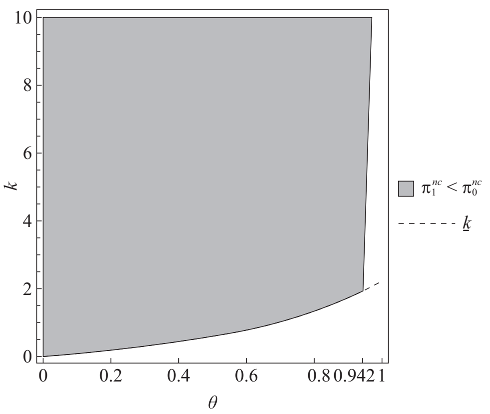
B.2 Proposition 4

FIGURE B.2. THE REGIONS OF $e_0^{nc}<e_1^{nc}$



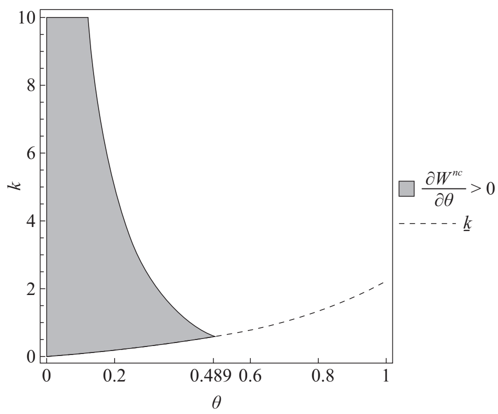
B.3 Proposition 5

FIGURE B.3. THE REGION OF $\pi_1^{nc} < \pi_0^{nc}$



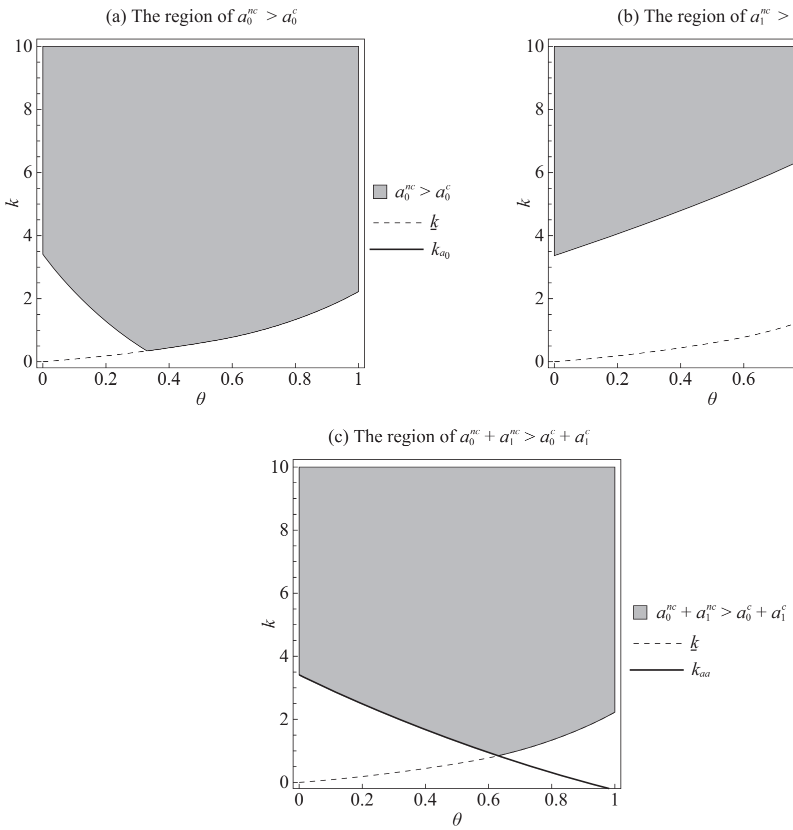
B.4 Proposition 6.4

FIGURE B.4. THE REGION OF $\frac{\partial W^{nc}}{\partial \theta} > 0$



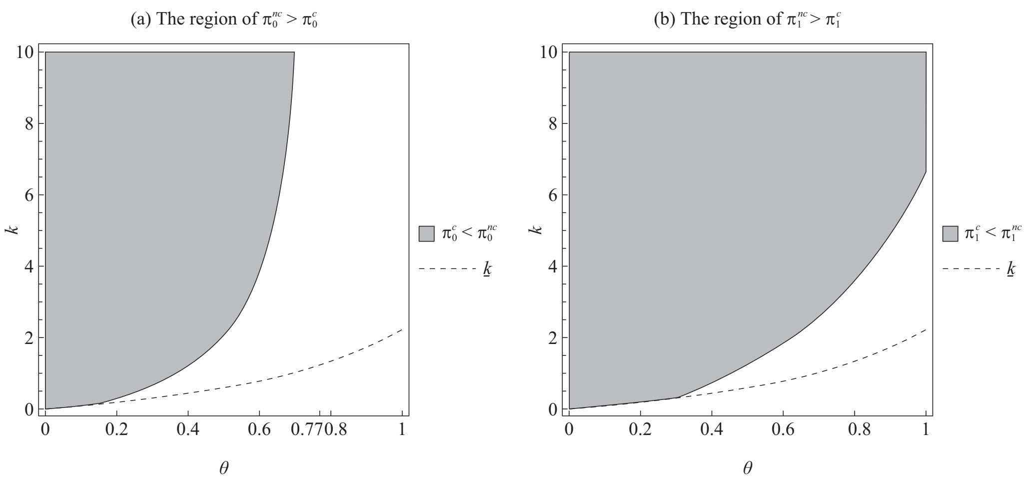
B.5 Proposition 8

FIGURE B.5. ABATEMENT COMPARISONS



B.6 Proposition 9

FIGURE B.6. PROFITS COMPARISONS



Appendix C. The Case with an Environmental CF Firm

Consider that firm 0 has the following objective function:

$$V_0 = \pi_0 + \theta(CS - ED) \quad \text{(C.1)}$$

where $CS - ED$ is net consumer surplus. Thus, CF firm is also conscious about the environment in a degree of θ. In the next analysis, we assume $k=1$ and compare the committed and non-committed policy regimes.

C.1 The Committed Policy Regime

The equilibrium abatement efforts and outputs, the optimal emission tax and resulting marginal environmental damage are the followings:

$$t^c = \frac{147456 - 81920\theta + 130816\theta^2 + 15360\theta^3 - 151104\theta^4 - 672\theta^5 + 441\theta^6}{\Omega} \quad \text{(C.2)}$$

$$a_0^c = \frac{32(4608 + 45444\theta + 1264\theta^2 + 644\theta^3 - 245\theta^4)}{\Omega}$$

$$a_1^c = \frac{32(4608 - 5440\theta + 5456\theta^2 - 804\theta^3 + 35\theta^4)}{\Omega}$$

$$q_0^c = \frac{8(30720 + 3840\theta + 119904\theta^2 + 8032\theta^3 - 544\theta^4 - 273\theta^5)}{\Omega}$$

$$q_1^c = \frac{8(30720 - 145920\theta + 13696\theta^2 - 5408\theta^3 - 224\theta^4 + 147\theta^5)}{\Omega}$$

$$MED^c = \frac{16(12288 - 3584\theta - 640\theta^2 + 1632\theta^3 + 36\theta^4 - 63\theta^5)}{\Omega}$$

$$\pi_0^c = 64\left(\frac{\begin{array}{c}1585446912 - 9673113360\theta + 10378280096\theta^2 - 1845248000\theta^3 - 852418856\theta^4 + 433249928\theta^5 \\ -142243072\theta^6 + 22831168\theta^7 + 9035024\theta^8 + 38178\theta^9 - 171549\theta^{10}\end{array}}{\Omega^2}\right)$$

$$\pi_1^c = 64\left(\frac{\begin{array}{c}1585446912 - 15335424000\theta + 18690867720\theta^2 - 11669749976\theta^3 + 5025628816\theta^4 - 982031136\theta^5 \\ -22241024\theta^6 + 134322224\theta^7 - 11105592\theta^8 - 287826\theta^9 + 40131\theta^{10}\end{array}}{\Omega^2}\right)$$

$$W^c = \frac{16(18432 - 5376\theta + 6720\theta^2 + 352\theta^3 - 964\theta^4 - 63\theta^5)}{\Omega}$$

where $\Omega \equiv 1130496 - 401408\theta + 554752\theta^2 - 50176\theta^3 - 24832\theta^4 + 672\theta^5 + 441\theta^6 > 0$.

Proposition C. 1 *Under the committed policy regime,* $t^c \lesseqgtr MED^c$ *if* $\theta \lesseqgtr \bar{\theta} \approx 0.733$, *where* $\bar{\theta}$ *is such that* $t^c(\bar{\theta}) = MED^c(\bar{\theta})$.

C.2 The Non-committed Policy Regime

The equilibrium abatement efforts and outputs, the optimal emission tax and resulting marginal environmental damage are the followings:

$$a_0^{nc} = \frac{3(768 + 1080\theta - 580\theta^2 - 25\theta^3)}{2(18 - 5\theta)\Delta} \tag{C.3}$$

$$a_1^{nc} = \frac{2304 - 3080\theta + 1340\theta^2 + 75\theta^3}{2(18 - 5\theta)\Delta}$$

$$q_0^{nc} = \frac{152 + 4\theta + 15\theta^2}{\Delta}$$

$$q_1^{nc} = \frac{152 - 60\theta - 5\theta^2}{\Delta}$$

$$t^{nc} = \frac{24 - 4\theta + 25\theta^2}{\Delta}$$

$$MED^{nc} = \frac{2(88 - 48\theta + 5\theta^2)}{\Delta}$$

$$\pi_0^{nc} = \frac{88501248 - 1067074560\theta + 293831040\theta^2 + 89238400\theta^3 - 5265200\theta^4 + 466000\theta^5 - 206250\theta^6}{8(18 - 5\theta)^2\Delta^2}$$

$$\pi_1^{nc} = \frac{88501248 - 1137208320\theta + 477680000\theta^2 - 75651200\theta^3 + 20932000\theta^4 - 604000\theta^5 - 356250\theta^6}{8(18 - 5\theta)^2\Delta^2}$$

$$W^{nc} = \frac{133788672 - 1394380800\theta + 485580160\theta^2 - 4628160\theta^3 + 533200\theta^4 - 453000\theta^5 - 31250\theta^6}{4(18 - 5\theta)^2\Delta^2}$$

where $\Delta \equiv 632 - 180\theta + 25\theta^2 > 0$.

Proposition C. 2 *Under the non-committed policy regime, $t^{nc} < MED^{nc}$ for any $\theta \in (0, 1)$.*

C.3 Comparing Policy Regimes

Proposition C. 3 *$t^{nc} < t^{c}$ for any $\theta \in (0, 1)$.*

Proposition C. 4

1. *$\pi_0^c < \pi_0^{nc}$ for any $0 < \theta < \theta_{\pi_0} \approx 0.44013$ where θ_{π_0} satisfies that $\pi_0^c(\theta_{\pi_0}) = \pi_0^{nc}(\theta_{\pi_0})$;*
2. *$\pi_1^c < \pi_1^{nc}$ for any $\theta \in (0, 1)$.*

Proposition C. 5

1. $ED^c < ED^{nc}$ for any $\theta \in (0, 1)$;
2. $W^c > W^{nc}$ for any $\theta \in (0, 1)$.

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