CHAPTER 6

CONCLUSION

In Chapter 5, it is applied a mathematical method to answer the research questions that are to find an abatement behavior of firms in each policy, and analyze whether the safety valve policy can reduce an information gap compared with the pure policy.

This chapter summarizes and provides interpretation of the results which are found in the mathematical analysis. This chapter consists of a conclusion and interpretation of firms' abatement behavior, a conclusion and interpretation of information gap reducing, policy implications, and limitations and suggestions.

6.1 Firms' abatement behavior

For the questions related to firms' abatement behavior, there are three kinds of policies: tax policy, permit policy and safety valve policy. Firstly, it is importance to address the notation of abatement level variables in each policy in Table 6.1. The following part shows firms' abatement behavior of each policy separately.

Table 6.1

Abatement levels variables in each policy.

Policy			firms	period	Abatement	Total
Tax		non-strategic (first best)	1st	Firm A	q_{1T}^{A*}	q_{1T}^{*}
				Firm B	q_{1T}^{B*}	
			2nd	Firm A	q_{2T}^{A*}	q_{2T}^{*}
				Firm B	q_{2T}^{B*}	
		strategic	1st	Firm A	$\hat{q}_{1T}^{A}$	$\hat{q}_{1T}$
				Firm B	$\hat{q}_{1T}^{B}$	
			2nd	Firm A	$\hat{q}_{2T}^{A}$	$\hat{q}_{2T}$
				Firm B	$\hat{q}_{2T}^{B}$	
Permit		non-strategic (first best)	1st	Leader	q_{1P}^{L*}	q_{1P}^{*}
				Follower	q_{1P}^{F*}	
			2nd	Leader	q_{2P}^{L*}	q_{2P}^{*}
				Follower	q_{2P}^{F*}	
		strategic	1st	Leader	$\hat{q}_{1P}^{L}$	$\hat{q}_{1P}$
				Follower	$\hat{q}_{1P}^{F}$	
			2nd	Leader	$\hat{q}_{2P}^{L}$	$\hat{q}_{2P}$
				Follower	$\hat{q}_{2P}^{F}$	
Safety Valve	Safety Valve does not work (Sn)	non-strategic (first best)	1st	Leader	q_{1Sn}^{L*}	q_{1Sn}^{*}
				Follower	q_{1Sn}^{F*}	
			2nd	Leader	q_{2Sn}^{L*}	q_{2Sn}^{*}
				Follower	q_{2Sn}^{F*}	
		strategic	1st	Leader	$\hat{q}_{1Sn}^{L}$	$\hat{q}_{1Sn}$
				Follower	$\hat{q}_{1Sn}^{F}$	
			2nd	Leader	$\hat{q}_{2Sn}^{L}$	$\hat{q}_{2Sn}$
				Follower	$\hat{q}_{2Sn}^{F}$	
	Safety Valve work (Sw)	non-strategic (first best)	1st	Leader	q_{1Sw}^{L*}	q_{1Sw}^{*}
				Follower	q_{1Sw}^{F*}	
			2nd	Leader	q_{2Sw}^{L*}	q_{2Sw}^{*}
				Follower	q_{2Sw}^{F*}	
		strategic	1st	Leader	$\hat{q}_{1Sw}^{L}$	$\hat{q}_{1Sw}$
				Follower	$\hat{q}_{1Sw}^{F}$	
			2nd	Leader	$\hat{q}_{2Sw}^{L}$	$\hat{q}_{2Sw}$
				Follower	$\hat{q}_{2Sw}^{F}$	

6.1.1 Tax policy

In the first period, both firms will choose to over-abate compared with an optimal level in order to induce the regulator to believe that they have low abatement cost. In the second period, the regulator will set low tax rate to equate tax rate with marginal benefit and marginal cost. Finally, in the second period which is the last period, firms can under-abate at a level that marginal cost equals to tax rate which is lower than optimal tax rate.

The reason why firms decide to over-abate in the first period instead of minimizing cost in each period separately. Although firms have to spend money more on abatement cost, they can reduce cost from tax payment. Later, in the second period, firms will receive low tax rate which made firms reduce cost per unit of emission as well as reduce an abatement level which results in low cost of abatement.

Table 6.2

An abatement behavior in tax policy

	1st period			regulator	2nd period		
Tax	Firm A	Firm B	Total		Firm A	Firm B	Total
	$\hat{q}_{1T}^{A} > q_{1T}^{A*}$	$\hat{q}_{1T}^{B} > q_{1T}^{B*}$	$\hat{q}_{1T} > q_{1T}^{*}$	$\hat{T}_2 < T_2^*$	$\hat{q}_{2T}^{A} < q_{2T}^{A*}$	$\hat{q}_{2T}^{B} < q_{2T}^{B*}$	$\hat{q}_{2T} < q_{2T}^{*}$

6.1.2 Permit policy

There are two cases of permit market: monopoly market and monopsony market.

Monopoly market

In monopoly market, the leader is a seller who is a permit price maker that behaves strategically. Follower is a buyer who is a permit price taker that behaves non-strategically. Follower always sets abatement level at the point where marginal cost equals to permit price. In order to maximize its own benefit, leader will attempt to distort the permit market in two ways.

Firstly, leader sets high price because he wants to sell permit at high price. This incentive is called a monopoly power. Secondly, leader sets high price to induce the regulator to believe that firms have high abatement cost because he wants more permit in the second period. This incentive is called permit's information power.

Therefore, from both monopoly power and permit's information power, leader will set permit price higher than an optimal price or over-pricing. In order to induce over-pricing, the leader has to under-abate, meanwhile, as a result of over-pricing, the follower will over-abate in the first period. Moreover, this induces the regulator to allow more permit than an optimal level in second period. Finally, the over-permit results in overall abatement level in second period which is less than an optimal level. In other words, there is overall under-abatement in second period.

Monopsony market

In monopsony market, leader is a buyer and follower is a seller of permit. Leader attempts to distort the permit market in two ways as same as in monopoly market. However, in monopsony market, these two powers push in opposite directions.

Firstly, the monopsony power is an incentive of leader to set permit price less than an optimal price or under-pricing. Secondly, the permit's information power is an incentive to set permit price greater than an optimal price or over-pricing.

From Table3, the condition $e_1^F - a_1^F - \hat{q}_1^F(\hat{p}_{a_1}) > \delta\left(\frac{\partial V_2^L\left(a_2^L, a_2^F\right)}{\partial a_2}\right)\cdot\frac{da_2\left(p_{a_1}\right)}{dp_{a_1}}$,

the left hand side is the amount of the demand that leader needs to buy. This amount is the marginal cost from increasing one unit of permit price. The right hand side presents the value of the saving that leader will get, which is the marginal benefit from increasing one unit of permit price. This condition means that the cost of permit buying that leader must pay to increase the permit price in the first period by one unit is less than the discounted value of cost reduction induced in second period. In other words, the marginal cost of increasing permit price is less than the marginal benefit. If this condition holds, it means permit's information power dominates monopsony power. As a result, leader will set over-pricing in the first period. Therefore, leader

will under-abate, and follower will over-abate in the first period. In addition, the over-pricing causing the regulator to issues greater than optimal amount of permits in the second period, which leads to overall under-abatement in the second period.

On the other hand, if the condition $e_1^F - a_1^F - \hat{q}_1^F(\hat{p}_{a_1}) < \delta\left(\frac{\partial V_2^L\left(a_2^L, a_2^F\right)}{\partial a_2}\right)\frac{da_2\left(p_{a_1}\right)}{dp_{a_1}}$ holds, it means that an increase of one unit of permit price leads to the increase in cost of the first period which is greater than the reduction of cost in the second period. To explain more precisely, monopsony power dominates permit's information power. Consequently, leader will be under price in the first period. This under-pricing causes leader to over-abate, and follower to under-abate in the first period. In addition, the under-pricing causing the regulator to issues less than optimal amount of permits in the second period, which leads to overall under-abatement in the second period.

Table 6.3

An abatement behavior in permit policy

		Condition	1st period			Regulator	2nd period
			Leader	Follower	Total		Total
Permit	Monopoly	-	$\hat{P}_{a_1} > P^*_{a_1}$ $\hat{q}^L_{1P} < q^{L*}_{1P}$	$\hat{q}^F_{1P} > q^{F*}_{1P}$	$\hat{q}_{1P} = q^*_{1P}$	$\hat{a}_2 > a^*_2$	$\hat{q}_{2P} < q^*_{2P}$
	Monopsony	$e^F_1 - a^F_1 - \hat{q}^F_1(\hat{p}_{a_1}) > \delta\left(\frac{\partial V^L_2\left(a^L_2, a^F_2\right)}{\partial a_2}\right)\cdot\frac{da_2\left(p_{a_1}\right)}{dp_{a_1}}$	$\hat{P}_{a_1} > P^*_{a_1}$ $\hat{q}^L_{1P} < q^{L*}_{1P}$	$\hat{q}^F_{1P} > q^{F*}_{1P}$	$\hat{q}_{1P} = q^*_{1P}$	$\hat{a}_2 > a^*_2$	$\hat{q}_{2P} < q^*_{2P}$
		$e^F_1 - a^F_1 - \hat{q}^F_1(\hat{p}_{a_1}) < \delta\left(\frac{\partial V^L_2\left(a^L_2, a^F_2\right)}{\partial a_2}\right)\cdot\frac{da_2\left(p_{a_1}\right)}{dp_{a_1}}$	$\hat{P}_{a_1} < P^*_{a_1}$ $\hat{q}^L_{1P} > q^{L*}_{1P}$	$\hat{q}^F_{1P} < q^{F*}_{1P}$	$\hat{q}_{1P} = q^*_{1P}$	$\hat{a}_2 < a^*_2$	$\hat{q}_{2P} > q^*_{2P}$

6.1.3 Safety valve policy

The analysis for safety valve policy will be divided into two cases, i.e., the case where permit price does not reach tax rate (or safety valve is not activated) and the case where permit price reaches tax rate (or safety valve activated).

6.1.3.1 Safety valve is not activated

In case that safety valve is not activated, the tax rate which the regulator set to be permit price ceiling is unused. The actions of firms are similar to the action in permit policy. Because tax that the regulator set to bound the price of permit is unused, firms will trade their permit in the same manner as in the permit policy. In this case, the only information that the regulator can observe is permit price because there is no excess emission from permit allowed. Additionally, there are two cases of permit market as same as permit policy: monopoly market and monopsony market.

The difference between safety valve policy and permit policy, in case that safety valve is not activated, is that leader will attempt to distort the permit market in three ways. There are the monopoly power, the permit's information power, and tax's information power. The tax's information power is an incentive of leader to distort information to induce the regulator to set tax rate in the way that is beneficial to leader.

Monopoly market

In monopoly market, the monopoly power, permit's information power, and tax's information power all create incentive for leader to set high price. Tax's information power can induce the regulator set higher tax rate in second period. This is matched with the leader want because he is a seller of permit. Because tax rate is a permit price ceiling, higher tax rate means that leader can sell permit at higher price.

Therefore, from all three powers, leader will set the over price and results in leader's under-abatement and follower's over-abatement in the first period. This over price induces the regulator to allow over permit and set over tax rate which lead to overall under-abatement in the second period.

Monopsony market

In monopsony market, leader is a buyer, and follower is a seller of permits. Leader prefers low permit price and low price ceiling. Hence, the monopsony power and tax's information power create incentive for leader to low price. On the other hand, the permit's information power creates incentive for leader to high price because leader prefers more amount of permit.

From Table4, the condition $e_1^F - a_1^F - \hat{q}_1^F(\hat{p}_{a_1}) > \delta\left[\frac{\partial V_2^L(.)}{\partial T_2(.)} \cdot \frac{\partial T_2(.)}{\partial p_{a_1}} + \frac{\partial V_2^L(.)}{\partial a_2(.)} \cdot \frac{\partial a_2(.)}{\partial p_{a_1}}\right]$ is similar to the permit policy but has the additional term of tax's information power.

The left hand side is the marginal cost of increasing one unit of permit price. The left hand side is always negative due to the fact that follower is seller in monopsony market.

The right hand side is the discounted increase in benefit (or reduction in cost) in second period from increasing one unit of permit price in the first period which is the marginal benefit. For this condition to hold, the right hand side must also be negative. In other words, an increase in permit price in the first period leads to the benefit from earning more permit which is greater than the cost of higher tax. It can be said that the permit's information power dominates tax's information power.

If this condition holds, the marginal cost of increasing permit price is less than the marginal benefit. In other words, the permit's information power to set high price dominates tax's information power and monopsony power to set low price. Leader will over-pricing in the first period which causes leader to under-abate, follower to over-abate and the regulator to over-permit in the second period; thus, leads to overall under-abatement.

On the other hand, the condition $e_1^F - a_1^F - \hat{q}_1^F(\hat{p}_{a_1}) < \delta\left[\frac{\partial V_2^L(.)}{\partial T_2(.)} \cdot \frac{\partial T_2(.)}{\partial p_{a_1}} + \frac{\partial V_2^L(.)}{\partial a_2(.)} \cdot \frac{\partial a_2(.)}{\partial p_{a_1}}\right]$ results in the opposite direction.

The left hand is always negative, but the right hand side can be negative or positive. If it is negative, it means that an increase in permit price in the first period

resulted in the benefit from earn more permit which is greater than the cost of higher tax. If it is positive, it means that an increase in permit price in the first period resulted in the benefit from earn more permit which is less than the cost of higher tax. It can be said that the tax's information power dominates permit's information power.

If this condition holds, the marginal cost of increasing permit price is greater than the marginal benefit. In other words, the monopsony power and tax's information power to set low price dominates permit's information power to set high price. Leader will under-pricing in the first period which causes leader to over-abate, follower to under-abate and the regulator to under-permit in the second period which leads to overall over-abatement.

Table 6.4

An abatement behavior in safety valve policy in case of safety valve is not activated

		Condition	1st period			Regulator	2nd period
			Leader	Follower	Total		Total
Safety valve (Safety valve is not activated)	Monopoly	-	$\hat{P}_{a_1} > P^*_{a_1}$ $\hat{q}^L_{1Sn} < q^{L*}_{1Sn}$	$\hat{q}^F_{1Sn} > q^{F*}_{1Sn}$	$\hat{q}_{1Sn} = q^*_{1Sn}$	$\hat{a}_2 > a^*_2$ $\hat{T}_2 > T^*_2$	$\hat{q}_{2Sn} < q^*_{2Sn}$
	Monopsony	$e^F_1 - a^F_1 - \hat{q}^F_1(\hat{p}_{a_1}) > \delta\left[\frac{\partial V^L_2(.)}{\partial T_2(.)} \cdot \frac{\partial T_2(.)}{\partial p_{a_1}} + \frac{\partial V^L_2(.)}{\partial a_2(.)} \cdot \frac{\partial a_2(.)}{\partial p_{a_1}}\right]$	$\hat{P}_{a_1} > P^*_{a_1}$ $\hat{q}^L_{1Sn} < q^{L*}_{1Sn}$	$\hat{q}^F_{1Sn} > q^{F*}_{1Sn}$	$\hat{q}_{1Sn} = q^*_{1Sn}$	$\hat{a}_2 > a^*_2$ $\hat{T}_2 > T^*_2$	$\hat{q}_{2Sn} < q^*_{2Sn}$
		$e^F_1 - a^F_1 - \hat{q}^F_1(\hat{p}_{a_1}) < \delta\left[\frac{\partial V^L_2(.)}{\partial T_2(.)} \cdot \frac{\partial T_2(.)}{\partial p_{a_1}} + \frac{\partial V^L_2(.)}{\partial a_2(.)} \cdot \frac{\partial a_2(.)}{\partial p_{a_1}}\right]$	$\hat{P}_{a_1} < P^*_{a_1}$ $\hat{q}^L_{1Sn} > q^{L*}_{1Sn}$	$\hat{q}^F_{1Sn} < q^{F*}_{1Sn}$	$\hat{q}_{1Sn} = q^*_{1Sn}$	$\hat{a}_2 < a^*_2$ $\hat{T}_2 < T^*_2$	$\hat{q}_{2Sn} > q^*_{2Sn}$

6.1.3.2 Safety valve activated

In a case of safety valve activated, the only information that the regulator can observe is excess emission which can refer to abatement level. The regulator cannot observe permit price because permit price equals to tax rate which is set by the regulator. Therefore, permit price does not reflect the firm's abatement cost function. There are still two cases of permit market: monopoly market and monopsony market.

Because in this case permit price is equal to tax rate; thus, leader cannot find the benefit from price adjustment. In order to maximize their own benefit, both firms will attempt to distort information in two ways: a tax's information power and permit's information power. These two incentives are conducted by distort abatement level from its optimal level.

Monopoly market

As leader is a seller, leader prefers higher tax rate as well as more permit in the second period. Therefore, from both incentives, leader will be under-abatement to induce the regulator to consider that firms have high abatement cost. Later on, the regulator will set high tax rate and allow more permit in the second period.

For the follower, in the monopoly market follower is a buyer. Therefore, there is a conflict between two incentives: an incentive to receive low tax rate incentive to earn more permit. Follower prefers lower tax rate in the second period; thus, the tax's information power of follower causes follower to over-abate in the first period. On the other hand, follower still prefers more permit, thus, the permit's information power causes follower to under-abate in the first period. If tax's information power dominates permit's information power, follower will over-abate. On the other hand, if permit's information power dominates tax's information power, follower will under-abate.

In the second period, there are two possible cases under the different conditions. In case that follower under-abate in the first period, both firms will under-abate. This is resulted in overall abatement levels are under-abatement. The regulator sets high tax rate and issues more amount of permit in the second period. Hence, by the high tax rate, firms over-abate in the second period. In the last period, firms always abate at level that marginal abatement cost equals to tax rate. Although they

earn more permit, it does not affect abatement level because firms already earn the benefit from more permit in the permit market. In case that safety valve is activated, a permit allowed help to reduce overall initial emission, but there is excess emission which firms have to pay tax for this. Therefore, when firms make their decision of abatement level in the last period, they always abate at marginal abatement cost equals to tax rate which is marginal cost of not abatement.

In case that follower over-abate in the first period, if leader's under-abatement is less than follower's over-abatement, the overall abatement levels are over-abatement. The regulator sets low tax rate and issues less amount of permit in the second period. Hence, by the low tax rate, firms under-abate in the second period. On the other hand, if leader's under-abatement is more than follower's over-abatement, then, overall abatement levels are under-abatement. The regulator sets high tax rate and issues more amount of permit in second period. Hence, by the high tax rate, firms over-abate in the second period.

Monopsony market

In case of safety valve activated, the result and the algorithm in monopsony market are the same as in monopoly market except that the role and the function between leader and follower are switched.

Table 6.5

An abatement behavior in safety valve policy in case of safety valve activated

	Condition	1st period			Regulator	2nd period		
		Leader	Follower	Total		Leader	Follower	Total
Monopoly market	$\frac{\partial T_2(.)}{\partial q_1}\cdot\left(e_2^F-\hat{a}_2^F-\hat{q}_2^F\right)+\frac{\partial a_2(.)}{\partial q_1}\left(-(1-\alpha)\hat{T}_2\right)>0$	$\hat{q}_{1Sw}^L < q_{1Sw}^{L*}$	$\hat{q}_{1Sw}^F < q_{1Sw}^{F*}$	$\hat{q}_{1Sw} < q_{1Sw}^*$	$\hat{a}_2 > a_2^*$ $\hat{T}_2 > T_2^*$	$\hat{q}_{2Sw}^L > q_{2Sw}^{L*}$	$\hat{q}_{2Sw}^F > q_{2Sw}^{F*}$	$\hat{q}_{2Sw} > q_{2Sw}^*$
	$\frac{\partial T_2(.)}{\partial q_1}\cdot\left(e_2^F-\hat{a}_2^F-\hat{q}_2^F\right)+\frac{\partial a_2(.)}{\partial q_1}\left(-(1-\alpha)\hat{T}_2\right)<0$		$\hat{q}_{1Sw}^F > q_{1Sw}^{F*}$	$\hat{q}_{1Sw} < q_{1Sw}^*$				
				$\hat{q}_{1Sw} > q_{1Sw}^*$	$\hat{a}_2 < a_2^*$ $\hat{T}_2 < T_2^*$	$\hat{q}_{2Sw}^L < q_{2Sw}^{L*}$	$\hat{q}_{2Sw}^F < q_{2Sw}^{F*}$	$\hat{q}_{2Sw} < q_{2Sw}^*$
Monopsony markrt	$\frac{\partial T_2(.)}{\partial q_1}\cdot\left(e_2^L-\hat{a}_2^L-\hat{q}_2^L\right)+\frac{\partial a_2(.)}{\partial q_1}\left(-\alpha\hat{T}_2\right)>0$	$\hat{q}_{1Sw}^L < q_{1Sw}^{L*}$	$\hat{q}_{1Sw}^F < q_{1Sw}^{F*}$	$\hat{q}_{1Sw} < q_{1Sw}^*$	$\hat{a}_2 > a_2^*$ $\hat{T}_2 > T_2^*$	$\hat{q}_{2Sw}^L > q_{2Sw}^{L*}$	$\hat{q}_{2Sw}^F > q_{2Sw}^{F*}$	$\hat{q}_{2Sw} > q_{2Sw}^*$
	$\frac{\partial T_2(.)}{\partial q_1}\cdot\left(e_2^L-\hat{a}_2^L-\hat{q}_2^L\right)+\frac{\partial a_2(.)}{\partial q_1}\left(-\alpha\hat{T}_2\right)<0$	$\hat{q}_{1Sw}^L > q_{1Sw}^{L*}$		$\hat{q}_{1Sw} < q_{1Sw}^*$				
				$\hat{q}_{1Sw} > q_{1Sw}^*$	$\hat{a}_2 < a_2^*$ $\hat{T}_2 < T_2^*$	$\hat{q}_{2Sw}^L < q_{2Sw}^{L*}$	$\hat{q}_{2Sw}^F < q_{2Sw}^{F*}$	$\hat{q}_{2Sw} < q_{2Sw}^*$

6.2 Information gap reduction

6.2.1 Safety valve is not activated

In case that safety valve is not activated, to find whether the safety valve policy can reduce the information gap is to compare safety valve policy with permit policy. There are two cases of permit market: monopoly market and monopsony market.

Monopoly market

The safety valve policy will reduce information gap compared to permit policy if the following condition holds,

$$\hat{C}_{qS}{}^{L}\left(\hat{q}_{1S}^{L}\right)-\hat{C}_{qP}{}^{L}\left(\hat{q}_{1P}^{L}\right)+\frac{e_1^F-a_{1S}^F-\hat{q}_1^F(\hat{p}_{a_{1S}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{e_1^F-a_{1P}^F-\hat{q}_1^F(\hat{p}_{a_{1P}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

$$<\quad \frac{\delta\left[\frac{\partial V_{2S}^L(.)}{\partial T_{2S}(.)}\cdot\frac{\partial T_{2S}(.)}{\partial p_{a_{1S}}}+\frac{\partial V_{2S}^L(.)}{\partial a_{2S}(.)}\cdot\frac{\partial a_{2S}(.)}{\partial p_{a_{1S}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{\delta\left[\frac{\partial V_{2P}^L(.)}{\partial a_{2P}}\cdot\frac{\partial a_{2P}(.)}{\partial p_{a_{1P}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}.$$

It shows that the difference of marginal cost combining with the difference of monopoly power between safety valve and permit policy are less than the difference of information power between the two policies.

Monopsony market

In order to compare information gap between safety valve policy and permit policy, four cases separated by firms' abatement behaviors are used.

I. The case that both safety valve and permit policies are over price in the first period.

In this case, the condition for information gap reduction is as same as in monopoly market that is

$$\hat{C}_{qS}{}^{L}\left(\hat{q}_{1S}^{L}\right)-\hat{C}_{qP}{}^{L}\left(\hat{q}_{1P}^{L}\right)+\frac{e_1^F-a_{1S}^F-\hat{q}_1^F(\hat{p}_{a_{1S}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{e_1^F-a_{1P}^F-\hat{q}_1^F(\hat{p}_{a_{1P}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

$$<\quad \frac{\delta\left[\frac{\partial V_{2S}^L(.)}{\partial T_{2S}(.)}\cdot\frac{\partial T_{2S}(.)}{\partial p_{a_{1S}}}+\frac{\partial V_{2S}^L(.)}{\partial a_{2S}(.)}\cdot\frac{\partial a_{2S}(.)}{\partial p_{a_{1S}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{\delta\left[\frac{\partial V_{2P}^L(.)}{\partial a_{2P}}\cdot\frac{\partial a_{2P}(.)}{\partial p_{a_{1P}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

It shows that the difference of marginal cost combined with the difference of monopsony power between safety valve and permit policy is less than the difference of information power between the two policies.

II. The case that both safety valve and permit policies are under price in the first period.

In this case, the safety valve policy can reduce information gap if the following condition holds.

$$\hat{C}_{qS}{}^{L}\left(\hat{q}_{1S}^{L}\right)-\hat{C}_{qP}{}^{L}\left(\hat{q}_{1P}^{L}\right)+\frac{e_1^F-a_{1S}^F-\hat{q}_1^F(\hat{p}_{a_{1S}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{e_1^F-\hat{a}_{1P}^F-\hat{q}_1^F(\hat{p}_{a_{1P}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

$$>\frac{\delta\left[\frac{\partial V_{2S}^L(.)}{\partial T_{2S}(.)}\cdot\frac{\partial T_{2S}(.)}{\partial p_{a_{1S}}}+\frac{\partial V_{2S}^L(.)}{\partial a_{2S}(.)}\cdot\frac{\partial a_{2S}(.)}{\partial p_{a_{1S}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}-\frac{\delta\left[\frac{\partial V_{2P}^L(.)}{\partial a_{2P}}\cdot\frac{\partial a_{2P}(.)}{\partial p_{a_{1P}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

, it shows that the difference of marginal cost combined with the difference of monopsony power between safety valve and permit policy is greater than the difference of information power between the two policies.

III. The case that in safety valve policy is over price but in permit policy is under price.

In this case, the safety valve policy can reduce information gap if the following condition holds.

$$\left[\hat{C}_{qS}{}^{L}\left(\hat{q}_{1S}^{L}\right)-C_{qS}{}^{L^*}\left(q_{1S}^{L^*}\right)\right]+\left[\hat{C}_{qP}{}^{L}\left(\hat{q}_{1P}^{L}\right)-C_{qP}{}^{L^*}\left(q_{1P}^{L^*}\right)\right]+\frac{e_1^F-a_{1S}^F-\hat{q}_1^F(\hat{p}_{a_{1S}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}+\frac{e_1^F-a_{1P}^F-\hat{q}_1^F(\hat{p}_{a_{1P}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

$$<\frac{\delta\left[\frac{\partial V_{2S}^L(.)}{\partial T_{2S}(.)}\cdot\frac{\partial T_{2S}(.)}{\partial p_{a_{1S}}}+\frac{\partial V_{2S}^L(.)}{\partial a_{2S}(.)}\cdot\frac{\partial a_{2S}(.)}{\partial p_{a_{1S}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}+\frac{\delta\left[\frac{\partial V_{2P}^L(.)}{\partial a_{2P}}\cdot\frac{\partial a_{2P}(.)}{\partial p_{a_{1P}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

, it shows that the distortion from the optimal marginal cost combined with the monopsony power from two policies is less than the information power from two policies.

IV. The case that in safety valve policy is under price, but in permit policy is over price.

In this case, the safety valve policy can reduce information gap if the following condition holds.

$$\left[\hat{C}_{qS}{}^{L}\left(\hat{q}_{1S}^{L}\right)-C_{qS}{}^{L^*}\left(q_{1S}^{L^*}\right)\right]+\left[\hat{C}_{qP}{}^{L}\left(\hat{q}_{1P}^{L}\right)-C_{qP}{}^{L^*}\left(q_{1P}^{L^*}\right)\right]+\frac{e_1^F-a_{1S}^F-\hat{q}_1^F(\hat{p}_{a_{1S}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}+\frac{e_1^F-a_{1P}^F-\hat{q}_1^F(\hat{p}_{a_{1P}})}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

$$>\frac{\delta\left[\frac{\partial V_{2S}^L(.)}{\partial T_{2S}(.)}\cdot\frac{\partial T_{2S}(.)}{\partial p_{a_{1S}}}+\frac{\partial V_{2S}^L(.)}{\partial a_{2S}(.)}\cdot\frac{\partial a_{2S}(.)}{\partial p_{a_{1S}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}+\frac{\delta\left[\frac{\partial V_{2P}^L(.)}{\partial a_{2P}}\cdot\frac{\partial a_{2P}(.)}{\partial p_{a_{1P}}}\right]}{\frac{\partial q_1^F(p_{a_1})}{\partial p_{a_1}}}$$

, it shows that the distortion from the optimal marginal cost combined with the monopsony power from two policies is greater than the information power from two policies.

6.2.2 Safety valve activated

In case that safety valve activated, to find whether the safety valve policy can reduce the information gap is to compare safety valve policy with tax policy. There are two cases of permit market: monopoly market and monopsony market.

Monopoly market

In order to compare information gap between safety valve policy and tax policy, two cases separated by firms' abatement behaviors are used.

I. The case that both firms over-abate in the first period in safety valve policy.

In this case, the safety valve policy can reduce information gap compared to tax policy if this following condition holds.

$$T_2'\left(\hat{q}_{1T}\right)\cdot\left(e_2^F-\hat{q}_{2T}^F\right)<\left[T_2'\left(\hat{q}_{1S}\right)\cdot\left(e_2^F-a_2^F-\hat{q}_{2S}^F\right)+a_2'\left(\hat{q}_{1S}\right)\left(-(1-\alpha)\hat{T}_{2S}\right)\right]$$

, it shows the change of tax rate in the second period multiplied with excess emission in tax policy of follower is less than the change of tax multiplied with excess emission

plus the change of permit multiplied with benefit from earning more permit in the second period of follower in safety vale policy. This condition means an information benefit of follower from tax distortion in tax policy is greater than information benefit from tax and permit distortion in safety valve policy.

If this condition does not hold, the safety valve policy may or may not reduce the information gap. This depends on an over-abatement level of follower in safety valve policy that is large enough to make total abatement level in safety valve policy which is greater than total abatement level in tax policy.

II. The case that both firms under-abate in the first period in safety valve policy.

a. Follower over-abate

In this case, the safety valve policy can reduce information gap compared to with tax policy if the following condition holds.

$$T_2'\left(\hat{q}_{1T}\right)\cdot\left(e_2^L-\hat{q}_{2T}^L\right)<-\left[T_2'\left(\hat{q}_{1S}\right)\cdot\left(e_2^L-a_2^L-\hat{q}_{2S}^L\right)+a_2'\left(\hat{q}_{1S}\right)\left(-\alpha\hat{T}_{2S}\right)\right]$$

, it shows the change of tax rate in the second period multiplied with excess emission in tax policy of leader is less than minus of the change of tax multiplied with excess emission in safety vale policy plus the change of permit multiplied with benefit from earning more permit in the second period of leader. This condition means an information benefit of leader from tax distortion in tax policy is greater than information benefit from tax and permit distortion in safety valve policy.

If this condition does not hold, the safety valve policy may or may not reduce information gap. It depends on under-abatement level of leader in safety valve policy. If leader's under-abatement level in safety valve policy is higher than follower's over-abatement level in safety valve policy plus over-abatement level in tax policy from both firms, $\left(q_{1S}^{L^*}-\hat{q}_{1S}^L\right)>-\left(q_{1T}^{L^*}-\hat{q}_{1T}^L\right)-\left(q_{1S}^{F^*}-\hat{q}_{1S}^F\right)-\left(q_{1T}^{F^*}-\hat{q}_{1T}^F\right)$, safety valve policy cannot reduce information gap.

b. Follower under-abate

In safety valve policy both firms under-abate, but in tax policy both firms over-abate. The safety valve policy can reduce information gap compared to with tax policy if these two following conditions hold.

$$T_2'\left(\hat{q}_{1T}\right)\cdot\left(e_2^L-\hat{q}_{2T}^L\right)<-\left[T_2'\left(\hat{q}_{1S}\right)\cdot\left(e_2^L-a_2^L-\hat{q}_{2S}^L\right)+a_2'\left(\hat{q}_{1S}\right)\left(-\alpha\hat{T}_{2S}\right)\right]$$

, this condition means as same as the previous case, and another condition is,

$$T_2'\left(\hat{q}_{1T}\right)\cdot\left(e_2^F-\hat{q}_{2T}^F\right)<-\left[T_2'\left(\hat{q}_{1S}\right)\cdot\left(e_2^F-a_2^F-\hat{q}_{2S}^F\right)+a_2'\left(\hat{q}_{1S}\right)\left(-(1-\alpha)\hat{T}_{2S}\right)\right].$$

It shows the change of tax rate in the second period multiplied with excess emission in tax policy of follower is less than the minus of the change of tax multiplied with excess emission in safety vale policy plus the change of permit multiply with benefit from earning more permit in the second period of follower. This condition means that an information benefit of follower from tax distortion in tax policy is greater than information benefit from tax and permit distortion in safety valve policy.

If this condition does not hold, the safety valve policy may or may not reduce information gap. This depends on under-abatement level in safety valve policy compared to over-abatement level in tax policy. If under-abatement level in safety valve policy is smaller than over-abatement level in tax policy, $\left(q_{1S}^{L*}-\hat{q}_{1S}^L\right)+\left(q_{1S}^{F*}-\hat{q}_{1S}^F\right)<-\left(q_{1T}^{L*}-\hat{q}_{1T}^L\right)-\left(q_{1T}^{F*}-\hat{q}_{1T}^F\right)$, then, safety valve policy can reduce an information gap.

Monopsony market

In case of safety valve activated, the result and the algorithm in monopsony market are the same as in monopoly market, but the role and the function between leader and follower are switched.

6.3 Policy implications

To implement policy in order to control firms' behavior, information that the regulator has is always less than firms have. Hence, asymmetric information always exists. According to the model presented in this study, if the regulator uses emission tax policy to control firms' abatement behavior, abatement level will be higher than optimal level. Firm will over-abate in the first period and will be under-abate in the second which is the last period.

It is commonly known that in perfect competition permit market is efficient, and permit price can illustrates firm abatement cost function very well. Thus, when the regulator uses emission permit policy or safety valve policy, the regulator must consider about permit market. If the policies are implemented in a market which is not large enough, the permit market may be not a competitive market. This uncompetitive market may lead to inefficient policy, and permit price may not demonstrate firm abatement cost function accurately.

For example, in a case of Thailand, if the government applies tradable permit system or safety valve policy in cement industry, the permit market is probably a monopoly market because there are only eight firms in cement industry. Moreover, the three biggest firms of eight firms earn around 80% of market share and, also, have better abatement technology. Hence, those three firms may perform as permit price maker, and the rest five firms must be price taker.

6.4 Limitations and Suggestions

Due to an attempt to make this study to be most general, this study uses an implicit function to find solutions. Thus, the solutions mainly inform the direction of abatement level and permit price. The solutions do not describe quantity or number. However, we can find reasonable explanations for conditional equations about firms' abatement behavior. Therefore, our findings in firms' abatement part are conclusive.

Unfortunately, in information gap reduction part, the interpretations of the conditional equations are found to be inconclusive. Attempts have been made to use

linear functional forms for marginal cost and marginal benefit functions. However, the conditional equations are still too complicated to explain intuitively.

Various approaches could be used to further address this limitation, e.g., to develop the explicit model in various functional forms and apply numerical study to find the solution numerically.