CHAPTER 3

THEORETICAL FRAMEWORK AND MODEL DESCRIPTION

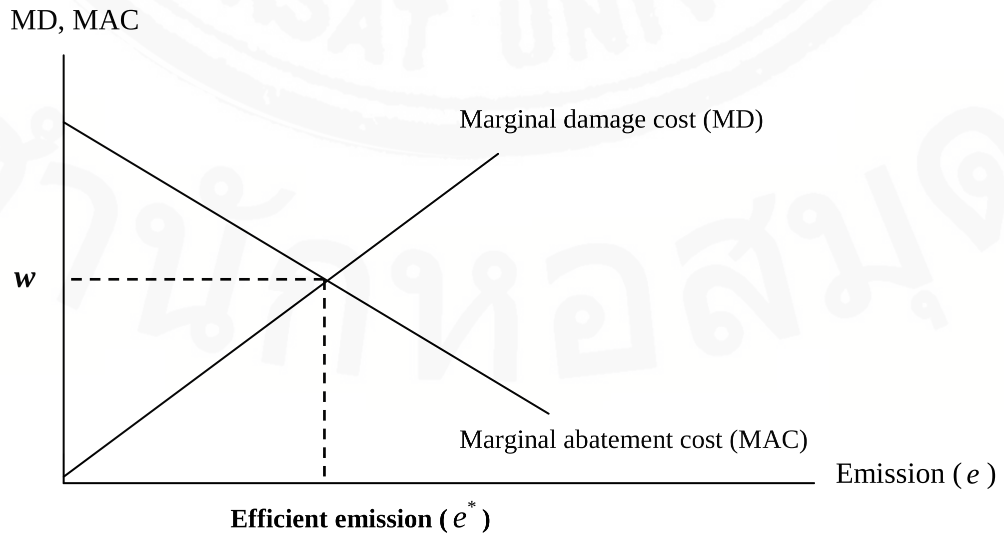
This chapter discusses theoretical framework in identifying optimal level of emission, as well as emission control under asymmetric information, and provides description of the model used in the analysis.

3.1 Optimal level of emission

According to Environmental Economics theory, the efficient level of emission is defined as the level at which marginal damages from emission are equal to marginal abatement costs. The reason is: higher emission exposes society to a greater cost stemming from environmental damages. Lower emission involves society in greater costs in the form of resources devoted to abatement activities. The efficient level of emission is; thus, the level at which these two types of costs exactly balance one another; that is, where marginal abatement cost equals to marginal damage cost, as in Figure3.1.

Figure3.1

The efficient level of emission

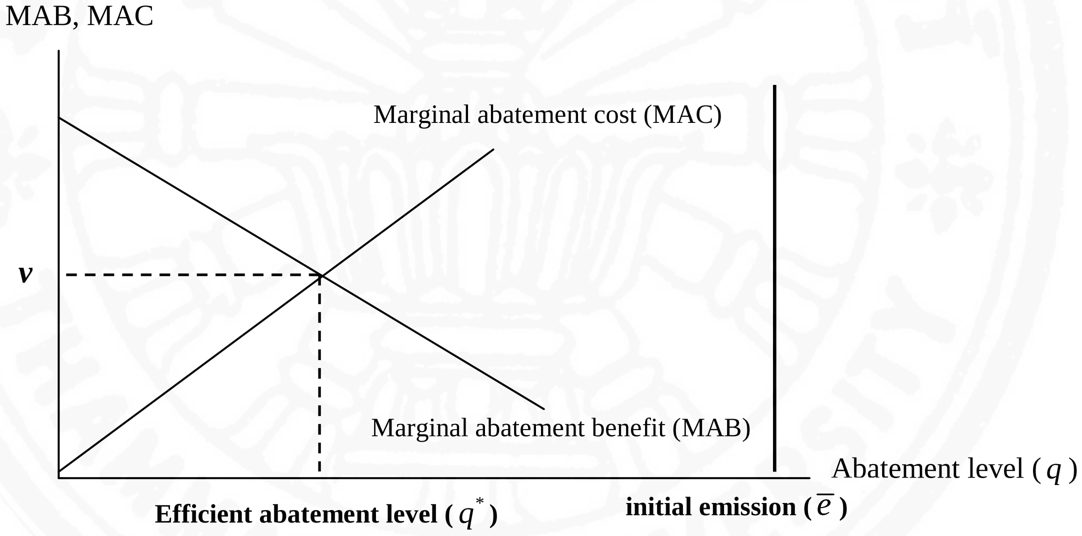


, where ***w*** is value of marginal abatement cost or marginal damage cost, at the point where the two costs are equal to each other.

Since this study assumed that production side is constant; thus, emission level is constant either. Hence, in the context of the model used in this study, the damage from emission could be inferred to as the abatement benefit. Therefore, the efficient level of emission, which in terms of abatement, is equivalent to the abatement level where marginal abatement cost equals to marginal abatement benefit, as shown in Figure3.2.

Figure3.2

The efficient abatement level

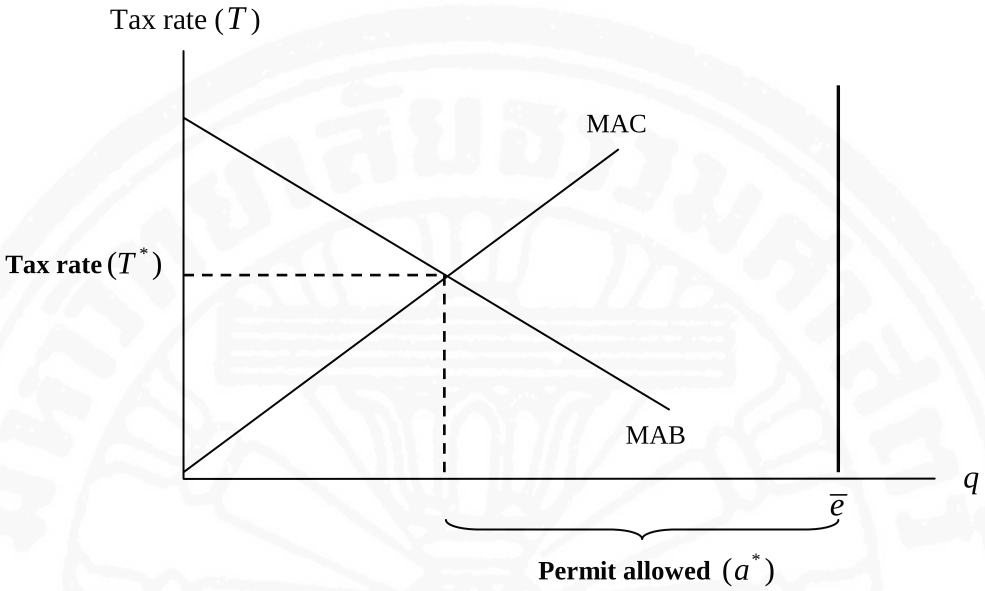


, where ***v*** is value of marginal abatement cost or marginal abatement benefit, at the point where their are equal to each other.

The regulator who aim to maximize social welfare have to set policy to control the abatement level where marginal abatement benefit is equal to marginal abatement cost. Therefore, with perfect information, the regulator would set the quantitative levels of each regulation policy – i.e., tax rate in tax policy, total permit amount in permit policy and both tax rate and permit amount in safety valve policy – at the point where marginal abatement benefit is equal to marginal abatement cost, as in Figure3.3.

Figure3.3

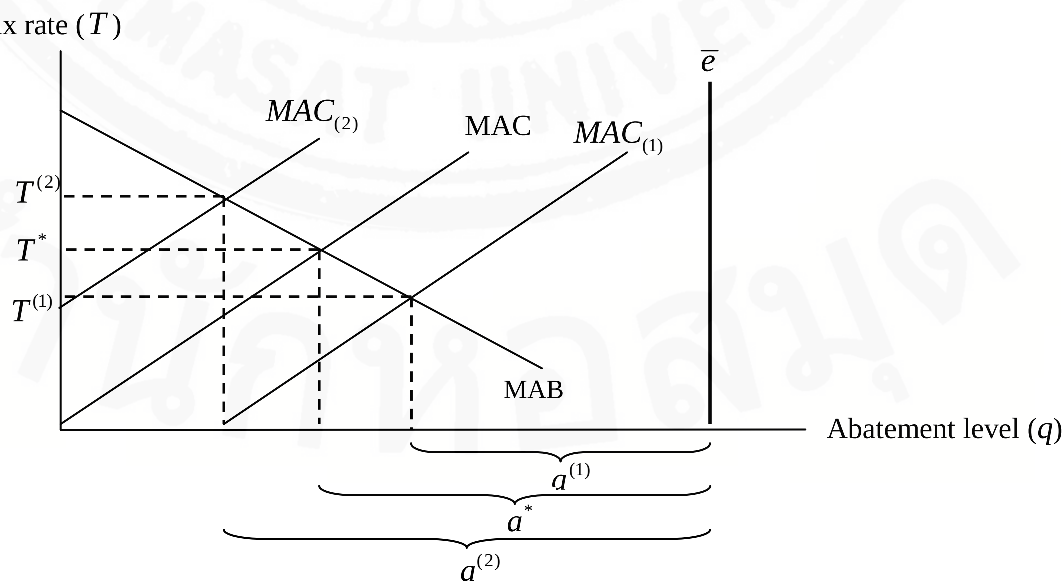
The efficient policy implementation



From Figure3.3, with perfect information, the regulator knows a true marginal abatement cost (MAC); thus, the regulator can set efficient tax rate and efficient amount of permit allowed. If the regulator set policy under asymmetric information, this policy may lead to inefficient policy, as in Figure3.4.

Figure3.4

The policy implementation under asymmetric information



From Figure3.4, with asymmetric information, marginal abatement cost, which the regulator use as information to set policy, may not be a true marginal abatement cost. The wrong marginal abatement cost ($MAC_{(1)}$ or $MAC_{(2)}$) will lead to an inefficient tax rate ($T^{(1)}$ or $T^{(2)}$), and inefficient permit allowed ($a^{(1)}$ or $a^{(2)}$).

3.2 Model Description

This part provides a narration about the model of this study. It is procedure in decision making of the regulator and two firms. Then, there are notation and assumption of the model in this study.

Firstly, it has to state that, there is two period model with one regulator and two firms. This study assumes that the regulator is always non-strategic, and firms are always strategic firms. In addition, there are three kinds of policy: emission tax, emission permit, and safety valve policy.

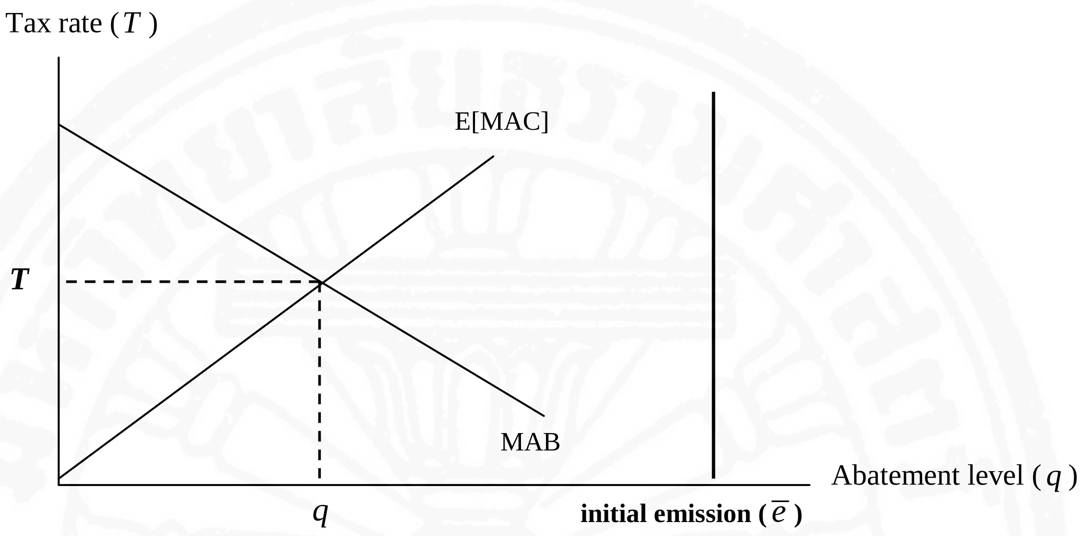
3.2.1 Tax policy

In tax policy, the regulator collects tax or charges of excess emission after abatement. Firms must tradeoff between cost of abatement and cost of paying tax.

In the first period, regulator, which has non-strategic behavior, sets emission tax rate such that marginal abatement benefit equals to expected marginal abatement cost, (MAB=E[MAC]). Because regulator believes that firms will abate at point where marginal abatement cost equals to tax rate (firm tradeoff between cost of abatement and regulatory cost or cost of non-abatement), so regulator will set tax rate to equal to marginal abatement benefit in order to induce firms to abate at marginal abatement cost equals to marginal abatement benefit as well as equal to tax rate (MAC = MAB = tax rate), as in Figure3.5. After tax rate is set, firms will plan to abate in order to minimize their cost (abatement cost plus regulatory cost or cost of non-abatement) by given tax rate.

Figure3.5

The regulatory mechanism to set tax rate in the first period

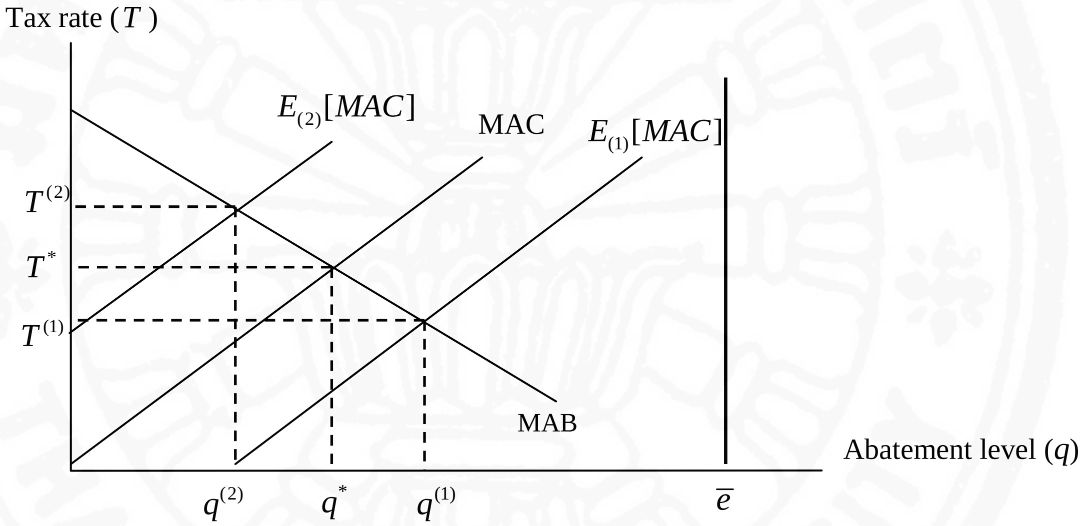


In the second period, regulator observes an abatement levels from firms and uses this information to set tax rate where marginal abatement benefit equals to expected marginal abatement cost as in the first period. Given tax rate, firms plan to abate in order to minimize their individual total cost.

These seem to be the best situation. Nonetheless, the problem is that firms are strategic. In other words, they know regulation mechanism. Firms know that their abatement levels are information for the regulator to set tax rate for them in the next period. Thus, when firms plan to abatement in each period, they try to manipulate regulator by their abatement level in order to minimize their long term cost, not just only at that period. Therefore, firms' behavior in each period optimally anticipates the effect of their action on the policy in the future. The firms' objective is to minimize the present value of their costs (abatement cost and regulatory cost). Because of the strategic behavior, the abatement level that regulator observed and uses it as information to set tax rate, does not reveal the real abatement cost of firm. The abatement level may be over-abatement or under-abatement from an optimal level. However, the regulator does not know the true information and believes that this abatement level is the real abatement cost of firm. The regulator uses this information to infer the firms' abatement cost function. Thus, an expected abatement cost function which the regulator infers may be higher or lower than real function. The regulator sets tax rate so that tax rate equals to marginal abatement benefit as well as equals to expected marginal abatement cost. Therefore, tax rate which the regulator set may be higher or lower than an optimal tax rate, as in Figure3.6. In the end, firms respond this policy with strategic behavior.

Figure3.6

The regulatory mechanism to set tax rate in second period



, where q is total abatement level

3.2.2 Permit policy

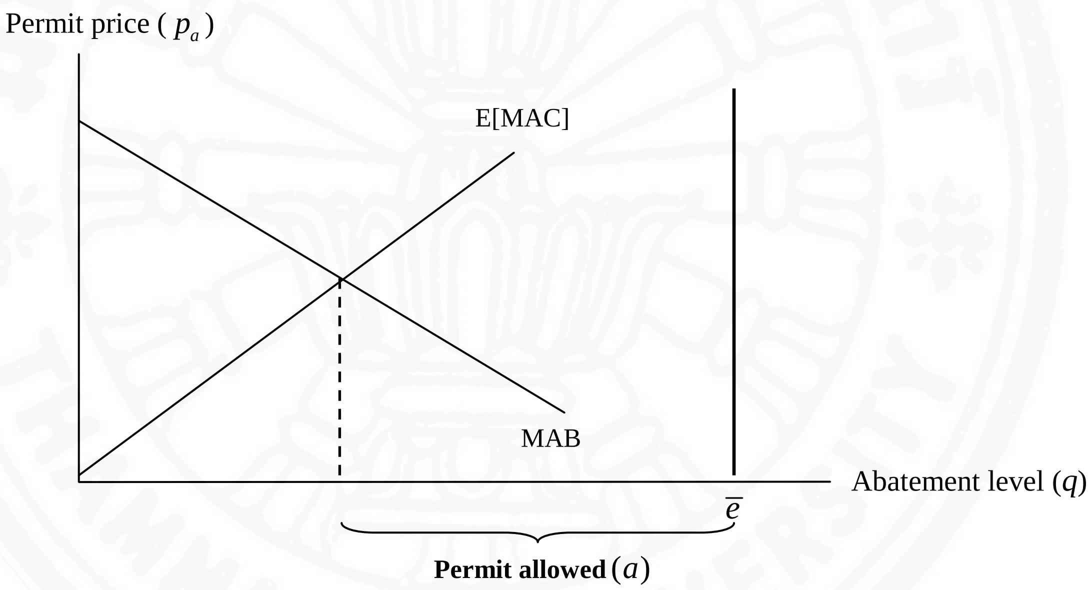
In permit policy, the regulator allocates marketable permit to firms, and the total emission cannot be more than the amount of permit allowed. Firms trade permit in order to minimize their own cost.

The procedure in permit policy is similar to in the tax policy. However, the regulator does not observe an abatement level. In permit policy, regulator observes a permit price trade between two separated firms. The firm that has more influence will have an authority to set the permit price; thus, become a permit price maker, and another firm will be a permit price taker. In each period, total emission must not exceed the total permit allowed.

In the first period, regulator allocates a tradable permit to two firms so that marginal abatement benefit equals to expected marginal abatement cost, as in Figure3.7. Firm which is a price maker will set the permit price by considering the received permit and the abatement level of price taker (price taker's reaction to permit price). Firm which is a price taker, will plan to abate by considering the received permit and the permit price that price maker set.

Figure3.7

The regulatory mechanism to set permit in the first period

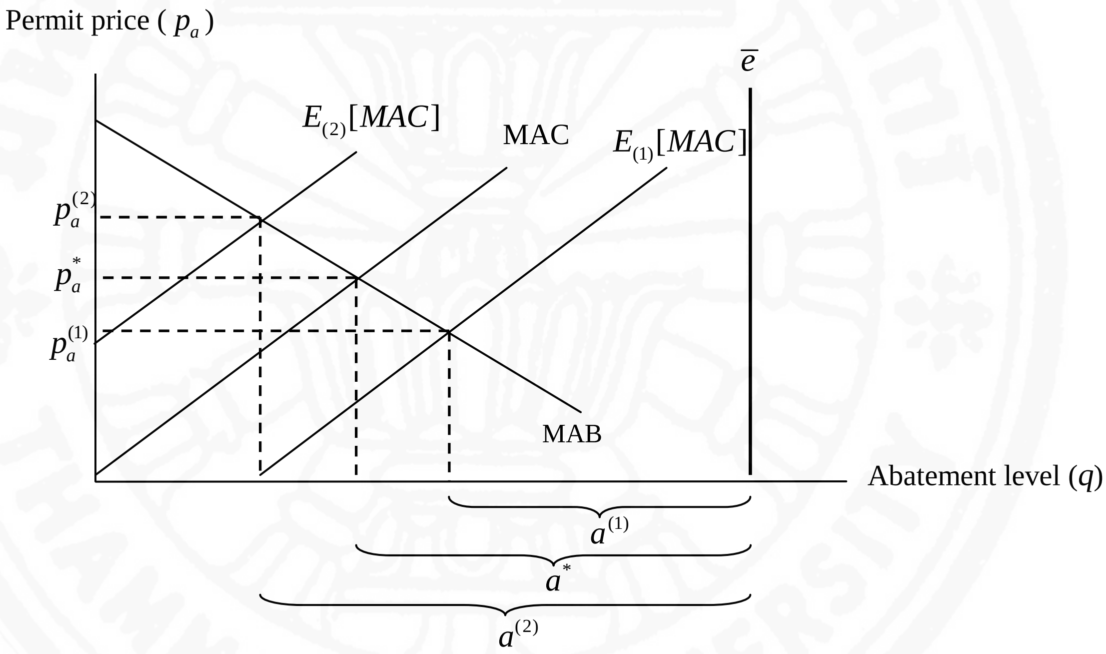


The procedure between firms is; at first the price maker will set the permit price with information of regulation mechanism and the price taker's reaction function. After permit price is set, the price taker will set an abatement level by considering a received permit and the permit price.

In second period, regulator observes a permit price and believes that firms trade permit at point where the market permit price equals to marginal abatement cost in the first period. With this belief, regulator infers the firms' abatement cost function and allocates permit where marginal abatement benefit equals to expected marginal abatement cost. However, permit price, which the regulator observes, may not reveal the real abatement cost. Hence, the price may be higher or lower than an optimal price. Thus, an expected abatement cost function which the regulator infers may be higher or lower than real function. Therefore, permit which the regulator allocated may be higher or lower than an optimal level, as in Figure3.8. In the end, firms respond to this permit level with strategic behavior.

Figure3.8

The regulatory mechanism to set permit in second period



In the permit market the two firms are engaged in a bilateral monopoly game. There is, of course, no unique solution to bilateral monopoly. Therefore, this study considers two extreme cases. In one case the seller of permit sets the permit price at which trade may occur, this case is akin to monopoly market. In the other case, the buyer of permit sets the permit price, this case is akin to monopsony market. In actual bargaining situations, typically both firms would have degree of bargaining power and the price would reflect the bargaining power of each firm.

3.2.3 Safety valve policy

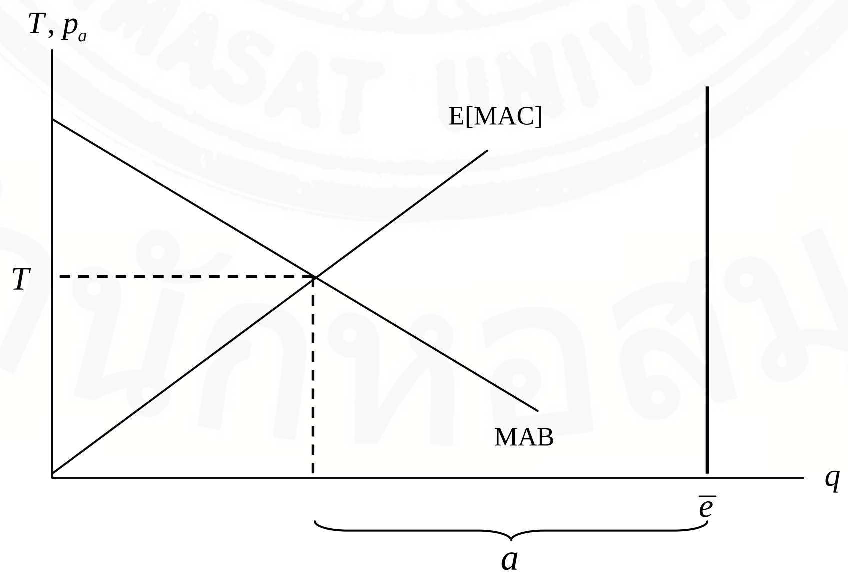
The idea of the safety valve policy is that the cost of capping emission can be limited. According to tax policy and permit policy, permit policy is preferable in terms of pollution control because it fixes the overall emission level while allows the permit price to vary. However, in a case that permit price is unfavorably high, permit policy yield a risk of injuriously high cost. Safety valve policy can cap the cost of compliance and reduces the risk of abatement cost that can be injuriously high. The regulator; therefore, offers permit sell in any quantity that is demanded at a predetermined price. In other words, the regulator sets tax rate as permit price ceiling. Therefore, if the permit price is greater than expected, then, marginal abatement cost would be limited to the safety valve price (tax rate).

In safety valve policy, the regulator allocates marketable permit and, also, set charges for pollution emission that exceeds the permit. Hence, in safety valve policy, the total emission can be greater than amount of permit, but firms have to pay tax for excess emission.

In the first period, regulator allocates permit to both firms and sets tax rate to charges for excess emission where marginal abatement benefit equals to expected marginal abatement cost, as in Figure3.9. At first, the permit price maker sets permit price to trade with price taker and uses this permit price to control price taker's abatement level.

Figure3.9

The regulatory mechanism to set permit and tax rate in the first period



In a case of monopoly market, price maker is a permit seller, seller will try to set high price. Seller can increase permit price if the seller knows that buyer still has excess demand for permit. Seller will increase price until there is no excess demand or until permit price reaches tax rate. Seller cannot set price greater than tax rate because buyer will not buy permit. Buyer will choose to pay tax because tax is cheaper. Hence, when permit price is less than tax rate, buyer tends to buy permit only. However, when price equals to tax rate, buyer will buy permit and pay tax for excess emission.

In a case of monopsony market, price maker is a permit buyer. Buyer will try to set low price, but seller will sell low number of permit. Thus, if buyer has excess demand for permit, buyer must increase permit price to induce seller to sell more permit. Buyer will increase price until there is no excess demand or until permit price reaches tax rate. Buyer will not set price greater than tax rate because permit cost will be higher than tax. Thus, when price is less than tax rate, buyer will choose to buy permit only. However, when price is equal to tax rate, buyer will buy permit and pay tax for excess emission.

In safety valve policy, permit price cannot be higher than tax rate either in monopoly market or monopsony market. Thus, there are two possible cases: safety valve is not activated which means permit price does not reach tax rate, and safety valve is activated which means permit price reaches tax rate.

In a case that safety valve is not activated, it means that firms use all permit that regulator allocates for them and have no excess emission. Therefore, regulator can observe only one signal from firms that is permit price. The regulator uses this information to set policy in the next period where marginal abatement benefit equals to expected marginal abatement cost. Firms plan to abate and trade permit with strategic behavior again. The procedure is similar to the procedure of permit policy.

In a case that safety valve activated, permit price equals to tax rate means that firms use all permit and still have excess emission. The regulator can observe only excess emission which can also imply for abatement level. Regulator will use this information to set policy in the next period where marginal abatement benefit equals to expected marginal abatement cost. Firms plan to abate and trade permit with strategic behavior again. The procedure is similar to the procedure of tax policy.

3.2.4 Notations and assumptions

The model description is the assumption of the model, notation of variables and assumption of abatement cost and abatement benefit.

There is two period model with one regulator and two firms. The two firms are permits seller (*s*) and permits buyer (*b*)

$C^j\left(q_t^j,\theta\right)$ is firm *j*'s abatement cost function in period *t* ; *j*={ *s* , *b* }

$C_q^j\left(q_t^j,\theta\right)$ is the marginal abatement cost function, assumed to be continuous

$C(q_t,\theta)=C^s(q_t^s,\theta)+C^b(q_t^b,\theta)$; $q_t^s+q_t^b=q_t$

$C_q\left(q_t,\theta\right)$ is the marginal aggregate abatement cost function

$E\left[C_q\left(q_t,\Theta\right)\right]$ is he expected marginal abatement cost function. This is for the regulator when the abatement cost function is unknown to the regulator.

$B\left(q_t\right)$ is the benefit from abatement in period *t*

where $e_t^j =$ Initial emissions by firm *j* in period *t*.

$q_t^j =$ Abatement levels by firm *j* in period *t*.

$e_t =$ Aggregate emissions in period *t*

$q_t =$ Aggregate abatement in period *t*

θ is a realization of random variable Θ, which known to firms but does not known by the regulator.

<u>Assumptions</u>

- marginal abatement cost function for each firm is positive, $C^j{}_q\left(q_t^j,\theta\right)>0$
- marginal abatement cost increasing in abatement, $C^j{}_{qq}\left(q_t^j,\theta\right)>0$
- if there is not abatement, there is not cost of abatement, $C^j\left(0,\theta\right)=0$
- increasing in θ result in a higher total abatement cost, $C^j{}_\theta\left(q_t^j,\theta\right)>0$
- increasing in θ result in a higher marginal abatement cost, $C^j{}_{q\theta}\left(q_t^j,\theta\right)>0$
- marginal abatement benefit is positive, $B'\left(q_t\right)>0$
- marginal abatement benefit declines in aggregate abatement, $B''\left(q_t\right)<0$
- $C_q\left(0,\theta\right)<B'\left(0\right)$ to ensure an interior optimal