Southeast Asian Journal of Economics 2(1), June 2014: 1-22

Applying Emission Tax and Emission Permit Schemes Controlling Greenhouse Gas Emissions in the Thai-Cement Industry: A Social Welfare Analysis

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Abstract

This paper aims to compare social welfare as a result of applying an emission tax scheme and emission permit schemes to see which scheme provides greater welfare to cement industry in Thailand. The goal is to meet a greenhouse gas emission reduction target. The method of the study consists of three steps including, 1) setting scenarios of emission taxes and emission permits in four different scenarios, 2) applying the Stackelberg model to a partial equilibrium theoretical analysis for the oligopoly cement market, 3) conducting numerical analysis to a social welfare function by using available data from the Thai cement industry. The results of the study show that the net social welfare via the emission permit approach is the best scenario in promoting the follower firms to voluntarity invest in emission reduction projects and allows them to sell the right to emit to the leader firm. These results also show incorporating an emission tax approach and emission permit regulation to both the leader and the follower firms provide the lowest net social welfare. The results of this study could be used as a case study for the domestic greenhouse gas control in the sector where the market structure is an oligopoly. In addition, it could provide relevant information for the Thai government to prepare a compulsory greenhouse gas reduction policy in the future considering social welfare.

Keywords: Emission Tax, Emission Permit, Social Welfare, Cement Industry

1. Introduction

It is known that the growth of greenhouse gas (GHG) emission is one of the global problems that caused climate change in several countries. This environmental problem demands a collaboration of responsibility among countries to internationally reduce GHG emissions. Although Thailand is non-Annex I country which has no binding GHG reduction commitment according to Kyoto Protocol, Thailand is encouraged to apply the new legal environmental instrument so as to achieve the appropriate level global temperature for the existence of life as well as sustainable long-term economic growth and social development. Consequently, it is interesting to study what economic approach can assist Thailand's GHG emission reduction target. Among emitted sectors in Thailand, the energy-intensive industry is one of the sectors that use plethora energy and release direct GHG emission from industrial process. Regarding to CO_2 emission contributed by the industrial process, the cement sector is the largest emitter, compared to glass, lime, pulp & paper, and iron & steel sectors. If the government considers social welfare as well as agrees to reduce national GHG emission, the cement sector may be the first targeted sector to control GHG emission. Since cement sector exploits domestic natural resources to construct infrastructure projects contributing economic development. Moreover, the market structure of Thai cement industry is an oligopoly one that could be an easy exercise to impose economic measure at the beginning. Thus, the objective of this study would like to compare social welfare of emission tax scheme and emission permit scheme as to which scheme provides greater welfare to the cement industry in Thailand in order to meet GHG emission reduction target. This study could be used to be an example for controlling emitted sector with oligopoly market structure. In addition, it will provide information to government of Thailand in order to impose the new legal environmental instrument in the future by taking social welfare into account.

2. Literature Review

The literature review can be divided into two parts which are 2.1) economic instruments for GHG control and 2.2) the economic figures of the cement industry in Thailand.

2.1 Economic Instruments for GHG control

Economic instruments for environmental management are mostly based on the concept of Polluter Pay Principle (PPP) to internalize the external or environmental costs into the cost of polluters (either producers or consumers). In general, most of environmental costs are generated by production. If the PPP is applied to private firms, the firm's production cost will increase and then the price of goods and services will be higher. The higher cost will induce producers to change their behaviors to produce less (as well as consumers to adjust their behaviors accordingly to higher price). The PPP will induce lower optimal production level and consequently lower level of GHG emissions.

Kaosa-ard and Rayanakorn (2009) presented several economic instruments for environmental management that can be applied in Thailand such as administration fees; user fees/charges; fines; pollution tax/fees; marketable or tradable permits; product surcharge; deposit-refund system; tax differentiation; performance bonds; and subsidy.

However, this study will focus only on emission tax and emission permit schemes which will be specifically applied to the oligopoly cement industry.

2.1.1 Emission Tax

There are many theoretical studies on emission tax with several types of market structures. Boumol and Oates (1988) studied a perfect competition market while other researchers studied imperfect competition markets. For example, Buchanan (1969) and Barnett (1980) studied monopoly, and Katsoulacos and Xepapadeas (1995) as well as Reinhorn (2005) studied oligopoly. From these theoretical studies, we found that an optimal degree of external cost internalization depends on the market structure. In perfect competition market, an optimal emission tax will equal the marginal external (or damage) cost. While in monopoly, the optimal tax will lower than the marginal damage cost. In contrast to in oligopoly, if it is included the positive effect of bringing the number of firms closer to the second best welfare optimal, the optimal tax will higher than the marginal damage cost.

In practices, several countries have used carbon tax (tax on carbon content) or energy taxes (tax on energy content) such as Finland, Netherland, Sweden, Denmark (these countries have used emission tax since 1990), England (since 2001) (Tantivasadakarn et al., 2009). From the lessons of several countries that applying carbon tax, we observe that 1) the tax rate is gradually increased with time, 2) the carbon tax rate is different from sources and fuels (In England, the tax rate of natural gas at a rate of 0.15 pence/kWh, LPG at a rate of 0.07 pence/kWh, the electricity usage at a rate of 0.44 pence/kWh), and 3) the collecting system is in a manner of revenue neutral; the fiscal revenues from tax are used to decrease other taxes so the government budget balance remains stable.

2.1.2 Emission Permit

Emission permit is a system that provides the rights to pollute, which allocates the permit to entities that release emissions. This system is not allowed entities to buy or sell the permits. This permit system is applied to control GHG emission by limited the amount of permit issued (in terms of ton of CO_2, for instance). Another system is cap-and-trade approach. Under this approach, a regulatory authority sets the total quantity of emissions that entities or participants are allowed to emit and allocates a number of tradable permit units. An entity who has lower abatement cost to reduce its emission internally below its allowance limit can sell unused allowance to other entities that have higher abatement cost in reducing their own GHG emission. The cap-and-trade approach or emission trading scheme (ETS) is generally called “carbon market”. The global carbon market can be categorized into two types: compulsory carbon market and voluntary carbon market. The compulsory carbon market, namely EU ETS, UK ETS, and NZ ETS, are widely accepted in Annex 1 Parties of UNFCCC. Voluntary carbon market is applied in various countries such as Switzerland, Japan, Australia, South Korea, India, US (e.g. Chicago Climate Exchange) and Taiwan.

There are similarities and differences in using carbon tax and carbon market. The similarities are increases in efficiency of resource and decreases the overall abatement cost of GHG emissions in the society (or in a certain involved sectors). Both systems encourage consumers and producers to change behaviors to meet the optimal resource allocation. The differences can be analyzed in many aspects such as administration cost, revenue transfer, price stability, and quantity of emission control (Sutummakid et al., 2009).

Currently both carbon tax and emission trading schemes are under widely discussion among academics, private sectors, and public institutions. Some economists such as Shapiro (2007) believes that carbon tax is more effective way to reduce GHG emissions than emission trading scheme because it is fair, transparent and non-volatile in carbon price.

2.2 The Economic Figures of Cement Industry in Thailand

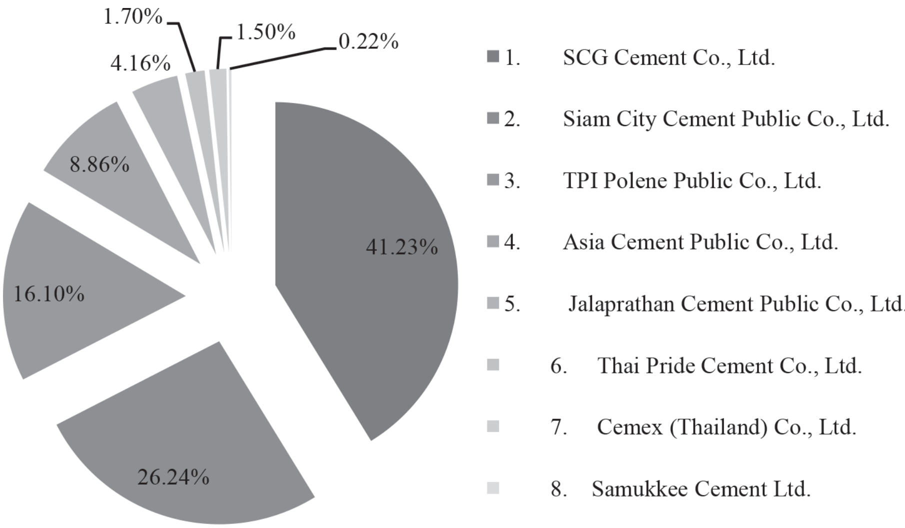
The first cement company in Thailand is SCG Cement Co., Ltd. (formerly known as Siam Cement Industry Co., Ltd), established in 1913 with production capacity 24,000 ton per year. The second one was Jalaprathan Cement Public Co., Ltd established in 1958 and Siam City Cement Public Co., Ltd established in 1972. Before 1990, there were barriers to entry in this industry such as no new company been approved by the government. Because of high demand for cement in the construction sector and public infrastructure, government allowed new companies to establish and former firms to extend their capacity to respond the high domestic demand. Nowadays (2013) there are 8 cement companies and have production capacity 56.35 million tons per year. SCG Cement Co., Ltd has the largest share of cement production capacity in Thailand, accounted for 41.23 % of total cement production capacity (Figure 1). If Thailand's cement production exceeds domestic demand, the excess can be exported (trend in 2004-2012 shown in Table 1). Major cement export markets in 2009 are Bangladesh, Vietnam, Cambodia, Myanmar, and UAE (OIE, 2010).

Table 1: Production, Demand, and Export of Cement Industry

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
Production (Million tons)	30.00	32.46	33.42	29.98	29.61	27.78	28.84	30.29	31.76
Domestic Demand (Million tons)	25.45	26.57	26.57	24.92	25.76	23.33	24.50	25.52	26.80
Domestic Demand Growth (%)	8.53	4.40	0.00	-6.21	3.37	-9.4	5.00	4.16	5.01
Clinker Exports (Million tons)	6.69	7.94	7.85	13.18	10.25	9.96	9.85	6.39	6.51
Cement Exports (Million tons)	4.55	5.89	6.85	5.06	3.85	4.45	4.35	4.77	4.96

Source: Thai Cement Manufacture Association (2013)

Figure 1: The Share of Cement Production Capacity in Thailand



Source: Thai Cement Manufacture Association (2013)

Regarding to cement production capacity in Thailand, we notice that over 80 percent of cement market share is controlled by only three big firms which are SCG Cement Co., Ltd, Siam City Cement Public Co., Ltd, and IPI Polene Public Co., Ltd. undoubtedly; the cement market structure in Thailand is an oligopoly one. In this study, three big firms will be called the leader firm and the others are called the follower firms.

3. Methodology

This section represents three steps of methodology employed in this analysis. The first step is setting the four scenarios of emission tax and emission permit schemes to compare social welfare. The next step is applying the Stackelberg model to analyze partial equilibrium (price and quantity of cement) in oligopoly cement market. The final step is conducting numerical analysis to social welfare in four scenarios using data from Thai cement industry, previous literature, and current price of carbon credits.

3.1 Scenarios

The study will be conducted based on four scenarios as shown in Table 2, i.e., one scenario of emission tax scheme and three scenarios of emission permit schemes. For emission tax scheme, we impose the emission tax to both leader and follower firms. In principle and practice, it is necessary to impose tax rate equally to all emitters. Therefore, only one scenario for emission tax scheme, i.e., Scenario 1, is considered which the same emission tax rate is imposed on all polluters. In this case, each firm will make a decision on reducing CO_2 emission based on the given emission tax rate and abatement cost according to available abatement technology.

For emission permit schemes, more scenarios are required for analysis. This is due to the complication and many issues that needed to be raised. Some of these issues include who should be capped or controlled, how permit should be distributed, possibility of trade permit in the sector, etc. Three scenarios (i.e., Scenario 2, 3 and 4) of emission permit schemes were chosen to be investigated in this study.

In Scenario 2, both leader and follower firms are controlled through emission permit; however, the expenses of these firms regarding the permit are different. Particularly, emission permit auction is applied to the leader firms while some free emission permits is given to the follower firms. Nevertheless, all firms have to abate the rest of their emission with their available abatement technology and abatement cost. Since most of the follower firms are small business with small market share, giving free emission permits would reduce their burden of the policy expenses. Moreover, since the leader firm may be able to access better abatement technology or lower abatement cost (or both), it is reasonable for them to reduce their own emission first and then their leftover will be charged by the government.

For Scenario 3 and 4, the measure is only provided to big polluters (i.e., the leader firm). In other words, the leader is allocated initial free emission permits and has to abate their CO_2 emission. On the other hand, the follower firms are excluded from the regulation. This is because the follower firms have smaller share of cement production capacity in total industry production which leads to smaller production and emission at the lower level.

In Scenario 3, the follower firms do not need to abate their emission. In Scenario 4, incentives are given to the follower firms to encourage them voluntarily to reduce emission using their own investment of emission reduction project. Specifically, the follower firms are given a right to sell carbon credits to the leader firm who releases emission at the high level corresponding to their outputs. The leader firm should firstly purchase carbon credits from the follower firms and then buy additional permits from the government when their credits do not enough to meet the desired production level.

Note that this study does not allow trading emission permit across the sectors and also does not consider emission from import and export of cement production. In other words, this study is only limited to domestic greenhouse gas control in the main emitter.

Table 2: Scenarios of Emission Tax and Emission Permit Schemes

	Tax Measure	**Permit Measure**		
	(1)	**(2)**	**(3)**	**(4)**
Leader Firm	Impose the same emission tax rate to the leader firm and the follower firm	Buy permit from the government in every desired CO_2 emitted to atmosphere	Get some free permit ($\bar{e}_1$) from government	-Get Free permit $\bar{e}_1$ -Buy CER from the follower's CDM[2], if he wants to emit more than $\bar{e}_1$ -Buy additional permit from the government when CER is not enough
Follower Firm		Get some free permit ($\bar{e}_2$) from government	Exclude from regulation	Invest in CDM-like project

Source: Author's Scenario

[2] Clean Development Mechanism is one of the Kyoto mechanisms. Its purpose has mutual benefit between developing countries (Non-Annex I of UNFCCC) and developed countries (Annex I of UNFCCC). The developing countries will benefit from project activity resulting in CER (Certified Emission Reduction) which it can sell to the developed countries. The developed countries can use CER to contribute to commitment of the Kyoto Protocol. In this study, the CDM-like project of the follower is not related to Kyoto Protocol.

This study assumes that the cement market is structurally an oligopoly and the emission market is perfect competition. Thus, the Stackelberg model will be applied to analyze the oligopoly cement market, leaving carbon market intact from any policy and firm's action in emission decision.

3.2 The Stackelberg Model

In Thai cement industry, there are three big firms which produce the higher production than the others, they are the leader in the industry. To simplify the strategic problem, we have to categorize the industry into 2 groups of firms, the leader firm and the follower firms according to the Stackelberg model. Under the Stackelberg model, the leader firm sets its output first and knows that the follower firms move sequentially playing Cournot strategy.

Therefore, it is given that Firm 1 is the leader firm and Firm 2 is the follower firms. The total cement's production (Q) is the summation of leader production (q_1) and follower production (q_2). Thus, $Q = q_1 + q_2$.

Assume that the inverse demand function takes the simple linear form as in (1)

$$P = f(Q) = a - bQ \tag{1}$$

where, P is the market cement's price, a is an intercept, b is a slope of demand function.

But the leader and the follower firms have different cost functions, $TC_i(q_i,\ e_i)$, which each function consists of total production cost (TPC_i), total abatement cost (TAC_i), and expense related to GHG reduction measure (e.g. emission tax, emission permit). It is assumed that the emission tax rate (t) is equal to the marginal damage cost of emission that caused by cement production, and the price of emission permit (P_p) is given by the government.

The total cost function in cases of emission tax and emission permit are shown in equation (2) and equation (3), respectively. These total cost function are the summation of total production cost (which depends on the amount of production), total abatement cost (which is a function of the CO_2 reduction attempt), and the expense on emission tax or emission permit schemes.

Emission tax: $TC_i(q_i, e_i) = TPC_i + TAC_i + t \cdot e_i$ (2)

Emission permit: $TC_i(q_i, e_i) = TPC_i + TAC_i + P_p.(e_i - \bar{e}_i)$ (3)

where, t is emission tax rate that is assumed to be correctly set by government to control CO_2 emission on the condition of the marginal abatement cost (MAC) is equal to the marginal damage cost (MDC) in cement industry. ($\sum_i MAC = \sum_j MDC = t$ Note that i = *firms and* j = *victims*.)

P_p is price of CO_2 emission permit that is given by the government.

$\bar{e}_i$ is the total amount of free permit allocated from government to *firm i*.

$TPC_i = g(q_i)$ depends on the quantity cement produced (q_i), $m_i = \dfrac{\partial TPC_i}{\partial q_i}$ is marginal production cost (private cost). It is assumed that other factors ($\bar{Z}$) are constant over the analysis of this study.

$TAC_i = h(\odot_i)$, where TPC_i is total abatement cost function, which depends on CO_2 reduction ($\odot_i$), $\odot_i = E_i - e_i$ is the amount of reduced CO_2 for firm $i = 1,2$

$\dfrac{\partial TAC_i(\odot_i)}{\partial q_i}$ is defined as $MAC_i(q_i)$ or the marginal abatement cost of an incremental cement output. It can be expressed as follow $\dfrac{\partial TAC_i(\odot_i)}{\partial q_i} = \dfrac{\partial TAC_i(\odot_i)}{\partial(\odot_i)}\dfrac{\partial(\odot_i)}{\partial q_i} = -MAC_i(e_i).\dfrac{\partial E_i}{\partial q_i}$. The marginal abatement cost of an incremental cement output is depended on the amount of CO_2 reduced (which is based on abatement technology which is expressed in term of $\dfrac{\partial E_i}{\partial q_i}$) and marginal abatement cost of emission. Thus, $MAC_i(e_i) = \dfrac{\partial TAC_i(\odot_i)}{\partial(\odot_i)}.\dfrac{\partial(\odot_i)}{\partial e_i} = \dfrac{\partial TAC_i(\odot_i)}{\partial(\odot_i)}.(-1)$

E_i is the maximum CO_2 generated by each firm. (It is depended on production of firms)

e_i is the amount of CO_2 emitted into the atmosphere.

After we solve theoretical model in oligopolistic cement market, we would get the equilibrium outcomes like the leader production (q_1^*), the follower production (q_2^*), total production (Q^*), the equilibrium price of cement (P^*) and then we can formulate social welfare function in equation (4) which consists of consumer surplus (*CS*) and producer surplus in the domestic cement market of leader (PS_1) and follower (PS_2) plus government revenue from measure (G) minus damage from existing emission in society

$$SW = CS + PS_1 + PS_2 + G - Damage \tag{4}$$

$$CS = \int_0^{Q^*} [a - bQ]dQ - P^* Q^* \tag{5}$$

$$PS_1 = P^* q_1^* - \sum TC_1(q_{1,} e_1) \tag{6}$$

$$PS_2 = P^* q_2^* - \sum TC_2(q_{2,} e_2) \tag{7}$$

$$G = Government\ Revenue \tag{8}$$

$$Damage = s \cdot \left(\sum_{i=1}^{n} e_i\right)^2, \text{ for s} > 0 \tag{9}$$

It is assumed that damage function is an increasing function of GHG emissions at rate s > 0, and the marginal damage cost is an increasing function of GHG emissions.

To compare the social welfare from emission tax scheme (SW^{TAX}) and the social welfare from emission permit scheme (SW^{PER}), this study considers four scenarios which, Scenario 1 belongs to emission tax measure, and three different ones are emission permit measures as a result of emission trading scheme is quite complicated and possess of many questions such as whom is capped by this measure? How emission permit is allocated to emitters? Can emitter buy right to emit across firms? Thus, we should analyze more in emission permit scenarios then they are provided in Scenario 2, Scenario 3, and Scenario 4.

3.3 Data and Assumptions on Numerical Analysis

<u>Demand Function</u>: Given that $P = f(Q) = a - bQ$, it is found that the domestic cement market demand estimated by Wongsopit (2010) can be $Q_t = 9.659615 - 1.545793PR_t$ where Q_t is domestic production clinker

equivalent (million ton/quarter) and PR_t is average Portland retailed price per quarter (1,000 baht/ton). Since total production of cement in year term is $Q = 4 \cdot Q_t$, then the adjusted demand function can be written as $P = 6.249 - 0.162Q$, where P is in term of 1,000 baht/ton and Q is in term of million ton per year.

Total Production Cost: $TPC_i = g(q_i)$ and $TPC_1 = m_1 \cdot q_1$ as well as $TPC_2 = m_2 \cdot q_2$, where $m_i = \frac{\partial TPC_i}{\partial q_i}$ is the marginal cost of production. In this study the marginal production cost of both the leader and follower will be assumed to equate the average production cost of Siam Cement Group (Table 3), that is $m_1 = m_2 = 2{,}140$ (baht/ton) which is five years (2006-2010) average cost.

Table 3: SCG Cement Consolidated Financial Information

	2010	**2009**	**2008**	**2007**	**2006**	**Average**
SCG Cement Consolidated Financial Information						
Net Sales (million baht)	48,954	46,661	49,999	44,087	44,123	46,764.8
Cost and Expenses (million baht)	41,189	38,649	42,124	36,943	35,431	38,867.2
The Retailed Prices (On average, according to specification)						
Mixed Cement Price (Elephant Brand) (baht/ton)	2,373.4	2,753.4	2,806.6	2,480	2,453.4	2,573.36
Production (million ton) = Net Sales/Mixed Cement Price	20.63	16.95	17.81	17.78	17.98	18.17
Average Production Cost (baht/ton) = Cost and Expenses/ Production	1,996.94	2,280.62	2,364.55	2,078.13	1,970.09	2,138.77

Source: Author's calculation an average based on www.scg.co.th and www.moc.go.th

Total Abatement Cost: Given that $TAC_i = h(\odot)$, it is assumed that the total abatement cost is $TAC_i(\odot_i) = \frac{1}{2}\beta_i A_i^2$, where $\odot_i = A_i = E_i - e_i$. Assume that marginal abatement cost of the leader and follower are $MAC_1 = \beta_1 A_1$ and $MAC_2 = \beta_2 A_2$, respectively. It is note that the leader firm has better abatement technology $\beta_1 = 1, \beta_2 = 2$. Theoretically, $MAC_1 = MAC_2 = MAC$ should provide the most efficient level of GHG reduced. Thus, for the simplicity, it is assumed that the marginal abatement cost of all firm are equal at optimal levels of GHG reduction of each firm. Therefore, $A_1 = \frac{MAC}{\beta_1}$, $A_2 = \frac{MAC}{\beta_2}$. The total amount of GHG abatement such that $A = A_1 + A_2$.

$$A = A_1 + A_2 = \frac{MAC}{\beta_1} + \frac{MAC}{\beta_2} = \frac{(\beta_1 + \beta_2)\cdot MAC}{\beta_1 \cdot \beta_2},\ MAC = \frac{\beta_1 \cdot \beta_2}{(\beta_1 + \beta_2)} \cdot A = \frac{2}{3} \cdot A$$

Regarding to the concept of the efficient level of GHG reduction (or emission) where price of CER equals to MAC, the MAC is assumed to be approximately 300 baht/tonCO2 (CER's price today is approximately 10 \$/tonCO2 with the exchange rate of 30 baht/\$). Thus, $MAC = 300 = \frac{2}{3} \cdot A$ and the total abatement level of $A = 450$ and hence $A_1 = \frac{MAC}{\beta_1} = \frac{300}{1} = 300$, $A_2 = \frac{MAC}{\beta_2} = \frac{300}{2} = 150$. Total abatement cost of the leader firm is $TAC_1(\odot_1) = \frac{1}{2}\beta_1 A_1^2 = \frac{1}{2}(1)\cdot(300)^2 = 45{,}000$. Total abatement cost of the follower firm is $TAC_2(\odot_2) = \frac{1}{2}\beta_2 A_2^2 = \frac{1}{2}(2)\cdot(150)^2 = 22{,}500$.

With the concept of efficient level of GHG reduction at firm level, emission tax rate should be equal to MAC. Thus, it is assumed that emission tax (t^*) = 300 baht/ton CO_2 and the each firm decides to emit under the condition of $t^* = MAC_i = \beta_i A_i = \beta_i \cdot (E_i - e_i^*)$ for $i = 1, 2$. The optimal emission (e_i^*) is equal to $E_i - \frac{t^*}{\beta_i}$. A study in Thailand found that a three-year (2006-2008) average of the carbon intensity of Thai cement industry is 0.84 ton CO_2/ton cement (Towprayoon et al, 2010). Since carbon dioxide is the major greenhouse gas[3] (GHG) emission from the cement industry, the parameter of emission intensity per output in the model is set to 0.84.

[3] The greenhouse gas emission is controlled in Kyoto Protocol has 6 types; CO_2, CH_4, N_2O, HFC, PFC, and SF_6

Therefore, the optimal emission of the leader firm is $e_1^* = q_1 - \frac{t^*}{\beta_1} = q_1 - \frac{300}{1} = q_1 - 300$, and the optimal emission of the follower firm is $e_2^* = q_2 - \frac{t^*}{\beta_2} = q_2 - \frac{300}{2} = q_2 - 150$. As given that $Damage = s.\left(\sum_{i=1}^{n} e_i\right)^2$, *for* $s > 0$, and under the efficient condition where emission tax rate should be set equal to the marginal damage cost, $t^* = 2 \cdot s \cdot \left(\sum_{i=1}^{2} e_i\right)$, thus $s = \frac{t^*}{2 \cdot \left(\sum_{i=1}^{2} e_i\right)} =$ 0.008729.

The summary of parameters used in numerical test is shown in Table 4.

Table 4: Parameters on Numerical Test

Parameter on Demand Function (Wongsopit (2010))	$a = 6{,}249$ (baht/ton-cement) $b = 0.162$ (baht/(ton-cement)^2)
Parameter in Production Cost (www.scg.co.th)	$m_1 = m_2 = 2{,}140$ (baht/ton-cement) $B = m_2 + 2m_1$ (baht/ton-cement)
Emission Tax Rate, Price of Permit, Price of carbon credit, Marginal Abatement Cost of Emission	$t = P_p = P_{CER} = MAC(e) = 300$ (baht/tCO_2)
Emission Intensity Per Output	$\frac{\partial E_1}{\partial q_1} = \frac{\partial E_2}{\partial q_2} = 0.84$ (tonCO_2/ton-cement)
Parameter on Damage Function	$s = 0.008729$ (baht/1000(tonCO_2)^2)

Source: Author's Synthesis

4. Results

4.1 Theoretical Results of Social Welfare in 4 Scenarios

The summation of all terms in social welfare function in equation (4) is reduced to equation (10). Each equation consists of 3 parts which are the same in every scenario but it is different in combinations (such as consumer surplus, leader's surplus, follower's surplus, government revenue, and damage). The first part is the net benefit of consumer surplus and the producer's revenue which is affected by the price and the quantity of production. The second part is the cost of production and abatement activity by firms which is affected by the cost and the level of production. The last part is the damage cost to environment which is affected by the level of emitted emission to atmosphere.

$$SW = \overbrace{\int_{0}^{Q^{*}} (a - bQ)dQ}^{\textit{Net benefit of consumer surplus and the producer's revenue}} - \underbrace{\left[\sum_{i=1}^{2} TPC(q_i) + \sum_{i=1}^{2} TAC_i(\odot_i)\right]}_{\textit{Cost of production and abatement activity by firms}} - \underbrace{Damage}_{\textit{Damage cost to environment}} \qquad (10)$$

The results of theoretical study in social welfare functions are shown in Table 5.

In first part, Scenario 3 and Scenario 4 provide the highest net benefit of consumer surplus and the producer's revenue. The consumer surplus in Scenario 3 (as well as in Scenario 4) is higher than that of Scenario 1 and Scenario 2 because consumer can consume more and face the lower's cement price.

In second part, total production costs are depended on the level of production. The total production of Scenario 3 is equal to that of in Scenario 4 so it provides the same level of total production of firms. In addition, the total production of Scenario 1 is equal to that of in Scenario 2 so it provides the same total production of each firm as well. Furthermore, the total abatement cost of the leader and the followers are depended on the amount of CO_2 reduced that differs among the leader and the follower firms.

In third part, the damage cost is the highest in scenario that giving free permit allocation to the leader and no GHG regulation to the follower (Scenario 3). The higher production of the follower firm without abatement activity, the higher the damage cost to environment is expected.

The summations of social welfare function in theoretical term are complicated to conclude which scenario provides the greatest social welfare in cement industry. Then, this study will further apply numerical analysis by using available data from Thai cement industry and previous literature to answer the objective of the study.

Table 5: Social Welfare Function from Emission Tax Scheme and Emission Permit Schemes

	Social Welfare Function = (1) + (2) - (3)		
	Consumer Surplus and Producer's Revenue	**Total Production Cost and Total Abatement Cost**	**Damage Cost**
Scenario 1	$\frac{1}{32b}\{15a^2 - 2a(T_2 + 2T_1 + B) - 2(T_2 + 2T_1)B - B^2 - (T_2 + 2T_1)^2\}$	$\sum_{i=1}^{2} TPC(q_i) + \sum_{i=1}^{2} TAC_i(\odot_i)$	$s \cdot (e_1 + e_2)^2$
Scenario 2	$\frac{1}{32b}\{15a^2 - 2a(F_2 + 2F_1 + B) - 2(F_2 + 2F_1)B - B^2 - (F_2 + 2F_1)^2\}$	$\sum_{i=1}^{2} TPC(q_i) + \sum_{i=1}^{2} TAC_i(\odot_i)$	$s \cdot (e_1 + e_2)^2$
Scenario 3	$\frac{1}{32b}\{15a^2 - 2aB - B^2 - 4aI_1 - 4BI_1 - 4I_1^2\}$	$\sum_{i=1}^{2} TPC(q_i) + TAC_1(\odot_1)$	$s \cdot (e_1 + E_2)^2$
Scenario 4	$\frac{1}{32b}\{15a^2 - 2aB - B^2 - 4aH_1 - 4BH_1 - 4H_1^2\}$	$\sum_{i=1}^{2} TPC(q_i) + TAC_1(\odot_1) + TAC^{CDM}{}_2(\odot_2)$	$s \cdot (e_1 + e_2)^2$

Note: a is an intercept, b is a slope of demand function. s is a parameter determined damage function, e_1 is CO2 emitted to atmosphere, E_i is the maximum CO_2 generated by each firm, $\odot_i = E_i - e_i$ is the amount of reduced CO_2, for $i = 1, 2$ $B = m_2 + 2m_1$, it determines the marginal production cost of firms. $T_1 = t.\frac{\partial E_1}{\partial q_1}$, $T_2 = t.\frac{\partial E_2}{\partial q_2}$, $F_1 = P_p.\frac{\partial E_1}{\partial q_1}$, $F_2 = P_p.\frac{\partial E_2}{\partial q_2}$, $I_1 = \frac{\partial TAC_1(\odot_1)}{\partial q_1}$, and $H_1 = P_{CER}.\frac{\partial E_1}{\partial q_1}$ are parameters that present the marginal abatement cost of an incremental cement output under several schemes.

4.2 Numerical Results

The numerical social welfare as a result of consumer surplus, producer surplus (the leader's surplus and the follower's surplus), government revenue, and damage are shown in Table 6.

Table 6: Numerical Social Welfare

Unit: Billion Baht

Social Welfare	Consumer Surplus	Producer Surplus		Government Revenue	Damage	Net Social Welfare
		Leader's Surplus	Follower's Surplus			
	(1)	(2)	(3)	(4)	(5)	=(1)+(2)+(3)+(4)-(5)
Impose Tax to Both Firms (1)	25.83	10.95	5.48	5.22	2.64	44.84
Leader Auction (2) & Follower's free permits is equal to desired level	25.83	10.95	7.22	3.48	2.64	44.84
Leader's free permits is equal to desired level (3)	26.96	12.79	8.21	0	2.81	45.15
Leader's free permits is equal to desired emission level &CDM (4)	26.96	12.74	8.23	0	2.76	45.17

Source: Author

Considering all components, the greatest net social welfare is presented in Scenario 4, and followed by Scenario 3. In contrast, the lowest net social welfare is shown in Scenario 1 and Scenario 2. If we analyze the net social welfare in composition, it shows that the benefits are different to stakeholders as the followings,

In consumer point of view, consumers are better off in Scenario 3 and Scenario 4, compared with Scenario 1 and Scenario 2 because they can consume more and face the lower cement's price.

In producer notion, the producer surplus is different as a result of the expenses on emission measures and the opportunity to create carbon credit though follower emission reduction project. The leader firm enjoys free permit allocation in Scenario 3 because the free permits give right to emit GHG without an additional abatement cost. When the leader is allocated the free permits equal to the desired level of emission, this provides the highest leader's surplus. While the follower firm enjoys no cap and the chance of investing emission reduction project for selling carbon credits to the leader firm in Scenario 4, it achieves the highest follower's surplus.

In government point of view, if the government objective is maximizing revenue, Scenario 1 (emission tax) generates the highest government revenue.

In environment aspect, the least environmental damage cost is presented when both emitters are controlled by emission measures (Scenario 1 and Scenario 2).

5. Conclusions

In Thailand, the cement sector is the largest emitter from the industrial process. In order to control emission of this sector, we can apply economic instruments that suit the characteristic of industry.

The objective of the study is to study whether emission tax scheme or emission permit scheme would give rise to greater social welfare in the cement sector in Thailand.

The Stackelberg model is applied in theoretical study of oligopoly cement market with four different scenarios of emission tax and emission permit schemes. These scenarios are 1) imposing the same emission tax rate to both the leader and the follower firms, 2) applying emission permits auction to the leader firm and giving some free permits to the follower firm, 3) giving free permits to the leader firm and excluding the follower firm from the regulation, and 4) giving some free permits to the leader firm and allowing the leader buy carbon credit from the follower firm who invests in CDM-like project. Finally, the study employs numerical test for social welfare function obtained from theoretical model by using available data of cement industry in Thailand and previous literature knowledge.

The result of the study shows that the greatest social welfare is the Scenario 4 that involving the follower firm voluntary investing CDM-like project and allowing the follower to sell CER-like to the leader firm. Social welfare in the emission tax scheme (Scenario 1) is equal to that of the emission permit auction to leader and providing initial free permits to follower (Scenario 2). In terms of stakeholder benefits are different among consumer, producer, and government. Consumer would prefer Scenario 3 and Scenario 4 than Scenario 1 and Scenario 2. The leader firm would prefer free emission permit measure. The follower firm would prefer Scenario 4. The government would prefer emission tax scheme because it generates the highest government revenue.

This study concludes that social welfare under emission permit scheme is higher than (or equal to) emission tax scheme. Moreover, various designs of emission permit scheme provide different results in social welfare. Among stakeholders, there are different points of view to prefer either emission tax measure or emission permit measure because they only concern their own benefits. To identify amount of GHG emitted to atmosphere and emission reduction activity (abatement level), the level of emission tax rate and price of permit are important. Regarding technology, the better technology of production, i.e., the lower emission intensity per output in polluting firms, can increase the social welfare.

Finally, the government should take more responsibilities to make stakeholders understand and take social welfare into consideration. When government chooses GHG measures, it is important to take damage cost into consideration in social welfare as well as consumer surplus and producer surplus.

6. Policy Implications

The analysis of social welfare of emission tax measure and emission permit measure can provide some recommendations to government as the followings. If government needs to promote the role of emission reduction project, CDM-like project is preferred because it helps to reduce the environmental damage from global warming impact and it provides the greatest social welfare to Thai cement industry, compared to other scenarios. If government would like to control GHG emitters via the emission permit measure, it can allocate free permit equal or less than the desired level of GHG (requested by the private sector) depending on the government purposes. If the government would like the permit scheme to be politically accepted by the emitters, the design of permit allocation system should be an incentive to involve all emitters. The higher amount of free permits allocated to firms, the higher producer surplus at the same level of production of firms. In another aspect, if the government wants to raise fund for the environment activities, the amount of free permit allocated to emitters can be set less than the desired level. This will induce emitters to buy more permits from the government (via auction or setting price of permit).

If government objective is maximizing revenue, emission tax scheme is preferred than the emission permit scheme. This is because (a) the emission tax is generally imposed to all emitters and (b) the emission tax is imposed on all GHG or CO_2 emitted which the emission permit scheme is mostly applied free permit allocation. However, the emission permit scheme can also generate revenue to the government if the whole amounts of permits are auctioned. If government wants to implement emission tax scheme, the lower emission tax rate the higher social economic welfare.

In the future, if Thai government has an international commitment to reduce GHG at national level or the developing countries, such as Thailand, are encouraged to apply the new legal environmental instrument, the government should foster the potential sector to voluntary reduce GHG by giving any of incentives to that sector. Moreover, to be ensure for emission reduction project investor, the government should identify emitters who cannot reduce the GHG emission buying carbon credits otherwise government may purchase all the credits.

There is a lesson learned from voluntary emission reduction in South Korea. Korea's government supports project development costs in emission reduction project and purchases Korea Certified Emission Reduction (KCERs) to provide rewards for mitigation actions and create motivations for voluntary carbon market, since 2007.

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