The Economic Incentive Policy Analysis of Extended Producer Responsibility (EPR)

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ABSTRACT

The paper pioneering introduces two economic incentive models, PLCEFM and PLCETM, to describe the efficiency of the EPR policy. The results of the research are as following: (1) adopts discrimination rate to final waste disposal is more effectiveness in encourage environmentally friendly designing by the firm; (2) if the price of the emission allowance is high enough, it facilitate green production by the firm; (3) if consumers increase their preference to the green products that can promote environmental design of the product by the firm; (4) if the rental price of abatement and environmentally friendly capital is high enough, then the trading allowance of PLC will improve environmental performance.

1. Introduction

Recently, lots of the researches have emphasized the need to move beyond government responsibility of environmental protection and to incorporate a much wider responsibility of producers. Extended producer responsibility (EPR) and environmental fee (or taxes) are two alternative ways of applying the polluter pays principle to waste products (e.g. packaging).[2] There are two objectives to be met: to discourage waste and to pay for its recycling/treatment (OECD, 2001). EPR is based on the explicit assumption that producers should be responsible for the environmental damage caused by their products. In addition, at least implicitly, there is an assumption that recycling these products generates more net economic benefit than using other methods of disposal such as incineration or landfill. EPR involves a voluntary agreement by producers within a sector to manage the collection and recycling of their product, sum of strengths and weakness of EPR is given in table 1.

Integrated product policies (IPP) is intended to an raise product issues in a comprehensive manner, by incorporating all tools, such as eco-labeling, EPR and green procurement, etc., that are product-related at a new level (Lin and Geiser, 2005), which are increasing receiving attention from policy makers both nationally and internationally. EPR is one of the key tools of the IPP, which is defined by Lindhqvist (2000) as a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufactures of the product to various parts of the entire life cycle of the product, and especially to the take-back, recycling and final waste disposal of the product (Spicer and Johnson, 2004). Bovea and Vidal (2004) pointed out consumers may increase their willingness to pay (WTP) to green products. Moreover, under the global supply chain of products, more environmental friendly production technology must get an advantage of the competition market in the future (Porter et al., 1995; Jaffe et al., 1995; Palmer et al., 1995).

Based on the social costs of Coase (1937) and Coase theory, the first concept of allowing rights to pollute was put forward by Dales (1968), suggesting the authorities to sell transferable rights to pollute. Hence, the authorities control the total amounts of

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[2] EPR is a policy approach in which producers accept significant responsibility (financial and/or physical) for the treatment or disposal of post-consumer products. Assigning such responsibility could provide incentives to prevent wastes at source, promote environmentally compatible product design and support the achievement of public recycling and materials management goals.(ECD,2001)

emissions, while the companies themselves decide the allocation of emissions amounts the actors. Later on, Montgomery (1972) mathematically showed the economical cost effectiveness of the tradable permits instrument.[3] Cerin and Karlson (2002) propose a concept for trading of product life cycle (PLC) emission rights, and the initial financial impacts of emissions and waste disposal from such PLC instruments are shown to become production costs, this provides economic incentives to take an increased responsibility for information flow as well as initiatives for product innovations.

Current strategies including environmental concerns have not led to a clear path towards sustainable development, since the major environmental effects from products generally appear as externalities, social costs, outside the legal boundary of the company providing products and systems. The aim of this paper is to propose a theoretic model, in which include both disposal fee and trading of PLC models to describe how to increase EPR efficiency. The remainder of this paper is structured as organized as follows. Section 2 analyzes final disposal fee issue. Section 3 describes life cycle emission trading system. Section 4 compares with previous two models. Section 5 concludes the paper.

Table 1. Strengths and Weakness of EPR

Strengths	Weakness
■ The aggregate cost is the actual cost of collection and recycling, so that in a direct sense, the pollution pays. ■ Fees paid by each producer can be calculated on a per unit basis to provide an incentive to reduce production. In this way the relative prices of the products are shifted to encourage more economic use of the product. ■ The scheme is designed by the sector itself, so that a high degree of compliance is to be expected. ■ It promotes recycling efforts, in line with agreed targets for total recycling goals by product.	■ It emphasis products rather than the materials; this may compromise the principle of equalizing marginal abatement costs across the economy. It also may provide only very indirect encouragement to switching towards producing products that use less harmful. ■ Producers outside the voluntary agreement can ride and have no incentive to modify their behavior. It may difficult to integrate imports into the system. ■ Voluntary agreements may risk encouraging overly co-operative (even collusive) behavior among firms.

Source: OECD (2001), OECD Economic surveys: Sweden.

2. Product Life Cycle Emission Fee Model (PLCEFM)

To extend producer responsibility , considering the government manages whole life cycle of the product , and impose the constant emissions and final disposal fee to

[3] Cost effectiveness means that use least cost to achieve a specific environmental quality.

the firm as well (including on-site and off-site pollutions),then the optimal control of the profit maximization model as follows：

$$Max \quad \int_0^T e^{-rt}\pi_{it}dt \tag{1}$$

$$s.t. \quad \pi_{it} = Pq_{it}(K_{ipt}) - v_p I_{ipt} - v_a I_{iat} - t_p e_{it} - t_q q_{it} \tag{2a}$$

$$\dot{K}_{ipt} = I_{ipt} - \delta_p K_{ipt} \tag{2b}$$

$$\dot{K}_{iat} = I_{iat} - \delta_a K_{iat} \tag{2c}$$

$$e_{it} = s_{it}(K_{ipt}) - h_{it}(K_{iat}) \geq 0 \tag{2d}$$

where π_{it} denotes profit of the firm；P is the constant price of product (assume perfect competition in output market)；q_{it} is quantity of output, which assume concave function of the production capital(K_{ipt}), i.e. $\partial q_{it}/\partial K_{ipt} > 0$ and $\partial^2 q_{it}/\partial K_{ipt}^2 < 0$; v_p, v_a are exogenous price of production(I_{ipt}) and abatement(I_{iat}) investment respectively; equation (2b) and (2c) are the motion functions of production(K_{ipt})and abatement(K_{iat})capital respectively; δ_p, δ_a are depreciation rate of K_{ipt} and K_{iat} respectively; e_{ipt} is on-site net pollutant emissions level, which equal to the total emissions ($s_{it}(K_{ipt})$) minus emission abatement ($h_{it}(K_{iat})$), and assume $\partial s_{it}/\partial K_{ipt} > 0$ and $\partial h_{it}/\partial K_{iat} > 0$；$t_p$， t_q are exogenous rate of pollutant emission and waste disposal respectively. The current Hamiltonian and the Lagrangian function show as follows (the subscripts of “i” and “t” are omitted)：

$$H_c = Pq(K_p) - v_p I_p - v_a I_a - t_p e - t_q q + \lambda_p(I_p - \delta_p K_p) + \lambda_a(I_a - \delta_a K_a)$$

$$\frac{\partial H_c}{\partial I_p} = -v_p + \lambda_p = 0 \tag{3}$$

$$\frac{\partial H_c}{\partial I_a} = -v_a + \lambda_a = 0 \tag{4}$$

$$\dot{\lambda}_p = -\frac{\partial H_c}{\partial K_p} + r\lambda_p = (t_q - P)\frac{\partial q}{\partial K_p} + t_p\frac{\partial s}{\partial K_p} + \lambda_p\delta_p + r\lambda_p \tag{5}$$

$$\dot{\lambda}_a = -\frac{\partial H_c}{\partial K_a} + r\lambda_a = -t_p\frac{\partial h}{\partial K_a} + \lambda_a\delta_a + r\lambda_a \tag{6}$$

In the steady state, let $\dot{\lambda}_p, \dot{\lambda}_a = 0$, then we get the equation (5a) and (6a):

$$\lambda_p = [(P - t_q)\frac{\partial q}{\partial K_p} - t_p \frac{\partial s}{\partial K_p}]/(\delta_p + r) \quad (5a)$$

$$\lambda_a = t_p \frac{\partial h}{\partial K_a}/(\delta_a + r) \quad (6a)$$

Substituting equation (5a) and (6a) into equation (3) and (4) respectively, yields:

$$(P - t_q)\frac{\partial q}{\partial K_p} = t_p \frac{\partial s}{\partial K_p} + v_p(\delta_p + r) \quad (3a)$$

$$t_p \frac{\partial h}{\partial K_a} = v_a(\delta_a + r) \quad (4a)$$

The economic meaning of equation (3a) indicates optimal K_p is determined by the value of marginal product (left hand side) equal to marginal factor cost (or called the user cost, right hand side). Equation (4a) shows optimal K_a is determined by the reduction of the payment of emission (marginal benefit of the abatement investment, left hand side) equal to the marginal costs of abatement investment (right hand side).

Although above model can partially illustrate producer's responsibility to the environmental improvement, however, it is less incentive to stimulate emission reduction production and eco-design of the products, Therefore, this paper furthermore analysis the impacts of discrimination waste disposal rate, [4] i.e. $t_q = t_q(q)$ and $\partial t_q / \partial q > 0$ (which denotes the emission fee is progressive with outputs level). Then, equation (3a) will be modified:

$$[P - (t_q + \frac{\partial t_q}{\partial q} q)]\frac{\partial q}{\partial K_p} = t_p \frac{\partial s}{\partial K_p} + v_p(\delta_p + r) \quad (3b)$$

Comparing equation (3a) and (3b), we can find the value of marginal production of K_P in the discrimination rate model is lower than the constant rate model, which implies lower production capital stock and pollution emissions, as well as less final waste disposal (i.e. increasing environmental performance in the country). Yields result 1:

Result 1:In the disposal fee model, discrimination rate policy is more environmental effectiveness than constant rate policy.

[4] This model considered the incentives of the eco-design. In other words, assuming emission rate is increasing function of products, it can induce the firms to reduce their pollution.

Although the discrimination rate system indeed can improve the environmental performance, however, it provides that production capital stock (K_p) decrease as well, means that results in economic loss. Hence, the researches will modify the system to focus on how to increase incentive to eco-design of the products, and facilitate both economy growth and environmental performance as well. Assuming disposal fee base on the degree of environmentally-friendly of the product, i.e. $t_d \hat{q}$,[5] where $\hat{q}$ denotes various degree of the environmentally-friendly products, and equal to environmentally friendly factor k multiplied output q, and k is decreasing function of the environmentally-friendly capital K_d,[6] that is $k = k(K_d)$, and $\partial k / \partial K_d < 0$, means more environmental capital stocks will result in the higher degree of environmentally-friendly products and less final waste disposal. Equilibrium equation K_P and K_d are:

$$[P - k(t_q + \frac{\partial t_q}{\partial \hat{q}} \hat{q})] \frac{\partial q}{\partial K_p} = t_p \frac{\partial s}{\partial K_p} + v_p(\delta_p + r) \qquad (3c)$$

$$-q(t_q + \frac{\partial t_q}{\partial \hat{q}} \hat{q}) \frac{\partial k}{\partial K_d} = v_d(\delta_d + r) \qquad (7a)$$

The left side of equation (7a) can rewrite as $-qt_q(1 + 1/\varepsilon_{t_q \hat{q}})$, where $\varepsilon_{t_q \hat{q}} = (\partial \hat{q} / \partial t_q)(t_q / \hat{q})$ is the elasticity of disposal fee, the economic meaning provides that additional increasing one unit of K_d will increase the environmentally-friendly degree of product ($-\partial k / \partial K_d > 0$), thus reduces final disposal rate (discrimination rate) and total expenditure of the disposal fee. Comparing equation (3b) with (3c), and if both of model's elasticity of disposal fee close enough, i.e. $\varepsilon_{t_q q} \approx \varepsilon_{t_q \hat{q}}$, then the value of marginal production of K_p will greater than previous model (since $0 < k < 1$), which means that the firms will invest more K_p, and achieve the purpose of economic growth. However, the total emissions (including on-site and off-site emission) is ambiguous, which is decided by the

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[5] Consider there are various emissions from the final disposal wastes be treated, we set another rate t_d in general.

[6] The green degree is measured by the degrees of recycled and reused, therefore, k become lower means higher proportion of recycled and reused, that is, the emissions of final disposal is less. In other words, $k = 1$ means the products does not recycle wastes at all.

performance of the final waste disposal reduction, if the latter effect greater than the front effect, net emission will decrease, then promote the whole environmental quality, that is called win-win strategy, yields

Result 2: *Incorporate the product eco-design mechanism (discrimination rate) into emissions fee policy will encourage company more environmentally friendly investment.*

Proposition 1. *If the green degree of the products is high enough, that is,* k *is small enough or* K_d *is high enough, it must favor economic growth, however, make not sure to worsen the environmental quality. In other words, it may achieve a win-win strategy.*

Waste products disposal (no matter what landfill and cremation) will emit pollutants, this paper will modify disposal fee in the front model to impose disposal emission fee, i.e., $t_d e_d$, and $e_d = e_d(\hat{q})$ is the non-decreasing function of $\hat{q}$. To simplify the analysis, we assume emissions are a linear function of $\hat{q}$, that is, $e_d = \beta\hat{q}$, where β is the emission intensive of $\hat{q}$, and $\beta \geq 0$; t_d is constant emission fee of $\hat{q}$. Optimal K_p and K_d equations will change as follows[7]:

$$(P - t_d \beta k)\frac{\partial q}{\partial K_p} = t_p \frac{\partial s}{\partial K_p} + v_p(\delta_p + r) \quad (3d)$$

$$-t_d q \beta \frac{\partial k}{\partial K_d} = v_d(\delta_d + r) \quad (7b)$$

From the equation (7b) we can find that β is one of key factors to decide optimal K_d, means that higher β will increase opportunity benefit of environmental investment, which improve environmental performance of the society. Comparing

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[7] In order to analysis how to decide environmental capital by the firm, we need to add a equation of motion, that is, the accumulation equation of the environmental capital (K_{idt}), which is $\dot{K}_{idt} = I_{idt} - \delta_d K_{idt}$, where I_{idt} is the environmental investment, and δ_d is the depreciation rate of the environmental capital.

equation (3c) and (3d), it finds that K_p is determined by t_q and $t_d\beta$, [8] due to $\beta \geq 0$, hence $t_q \geq t_d\beta$ is a sufficient condition of this model to get more productive investment than the front model.

Result 3: *If substitute final disposal fee base to emission fee base in the PLCEFM will induce more investment of the environmental capital, and result in higher environmental performance.*

Proposition 2. *Comparing emission base and waste disposal fee system, $t_q \geq t_d\beta$ is a sufficient condition to invest more K_p in the emission base.*

3. Product Life Cycle Emission Trading Model (PLCETM)

Following, we will further introduce product life cycle emission trading model (PLCTM), which including on-site and off-site emissions of firms, and discuss how the firm face emissions cap to decide the optimal investment, and comparing effects with the PLCEFM. The PLCETM describes as follows:

$$Max \quad \int_0^T e^{-rt}\pi_{ipt}dt$$

$$s.t. \quad \pi_{it} = Pq_{it}(K_{ipt}) - v_p I_{ipt} - v_a I_{iat} - v_d I_{idt} - P^T z_{it} \tag{8a}$$

$$\dot{K}_{ipt} = I_{ipt} - \delta_p K_{ipt} \tag{8b}$$

$$\dot{K}_{iat} = I_{iat} - \delta_a K_{iat} \tag{8c}$$

$$\dot{K}_{idt} = I_{idt} - \delta_d K_{idt} \tag{8d}$$

$$e_{ipt} = s_{it}(K_{ipt}) - h_{it}(K_{iat}) \geq 0 \tag{8e}$$

$$e_{idt} = \beta\hat{q}_{it} \tag{8f}$$

$$k_{idt} = k_{idt}(K_{idt}) \tag{8g}$$

$$e_{i0} = e_{ipt} + e_{idt} - z_{it} \tag{8h}$$

Where $z_{idt} > 0\,(<0)$ denotes buyer (seller) of the allowance permits of firm[9]; P^T is

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[8] Equation (3c) will change to $(P - kt_q)\dfrac{\partial q}{\partial K_p} = t_p\dfrac{\partial s}{\partial K_p} + v_p(\delta_p + r)$.

the exogenous price of allowance (suppose perfectly competition allowance market), the meanings of the other variables are the same as the previous model, not to define again. The current Hamiltonian and the Lagrangian function show as follows:

$$H_{tc} = Pq_{it}(K_{ipt}) - v_p I_{ipt} - v_a I_{iat} - v_d I_{idt} - P^T z_{it} + \lambda_p (I_{ipt} - \delta_p K_{ipt}) + \lambda_a (I_{iat} - \delta_a K_{iat}) + \lambda_d (I_{idt} - \delta_d K_{idt})$$

$$L_t = H_{tc} + \eta_t (e_{i0} - e_{ipt} - e_{idt} + z_{it})$$

Its optimal conditions show as follows (whether the subscript of "t" is omitted):

$$\frac{\partial L}{\partial I_p} = -v_p + \lambda_p = 0 \tag{9}$$

$$\frac{\partial L}{\partial I_a} = -v_a + \lambda_a = 0 \tag{10}$$

$$\frac{\partial L}{\partial I_d} = -v_d + \lambda_d = 0 \tag{11}$$

$$\frac{\partial L}{\partial z} = -P^T + \eta = 0 \tag{12}$$

$$\dot{\lambda}_p = -\frac{\partial L}{\partial K_p} + r\lambda_p = -P\frac{\partial q}{\partial K_p} + \eta(\frac{\partial s}{\partial K_p} + k\beta\frac{\partial q}{\partial K_p}) + \lambda_p \delta_p + r\lambda_p \tag{13}$$

$$\dot{\lambda}_a = -\frac{\partial L}{\partial K_a} + r\lambda_a = -\eta\frac{\partial h}{\partial K_a} + \lambda_a \delta_a + r\lambda_a \tag{14}$$

$$\dot{\lambda}_d = -\frac{\partial L}{\partial K_d} + r\lambda_d = \eta\beta q\frac{\partial k}{\partial K_d} + \lambda_d \delta_d + r\lambda_d \tag{15}$$

Assume in the steady state, let $\dot{\lambda}_p = \dot{\lambda}_a = \dot{\lambda}_d = 0$, and rearrange equation (9), (10) and (11) yield:

$$(P - P^T k\beta)\frac{\partial q}{\partial K_p} = P^T\frac{\partial s}{\partial K_p} + v_p(\delta_p + r) \tag{16a}$$

$$P^T\frac{\partial h}{\partial K_a} = v_a(\delta_a + r) \tag{16b}$$

$$-P^T q\beta\frac{\partial k}{\partial K_d} = v_d(\delta_d + r) \tag{16c}$$

Equation (16a), (16b) and (16c) denote optimal function of K_p, K_a and K_d respectively. Comparing above equations with (3d), (4a) and (7b), and for simply the

[9] Because this paper doesn't discuss banking mechanism and suppose the government could perfectly enforcement. So, the representative firm doesn't have cheating behaviors, and (8h) will be satisfied.

analysis, assume both of the process and waste disposal are identical emissions (e.g. CO_2), then $t_d = t_p$, and in the $t_p = P^T$ circumstance, the researches find that both of PLCETM and PLCEFM are equivalent. Thus

Result 4: *Under identical emissions of on-site and off-site assumption, and if* $t_p = P^T$, *both of PLCETM and PLCEFM are equivalent.*

To analysis comparative static issues, total differential equation (16a), (16b) and (16c), and use the Cramer's rule to solve the simultaneous equations (proofed see appendix A), and let

$$\Delta = -P^{T2}\beta\frac{\partial^2 h}{\partial K_a^2}\{q\frac{\partial^2 k}{\partial K_d^2}[(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T\frac{\partial^2 s}{\partial K_p^2}] + P^T\beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2\} < 0 ,$$

Obtains the effect P^T changes to K_p, K_a and K_d :

$$\frac{dK_p}{dP^T} = \frac{P^{T2}q\beta\frac{\partial^2 h}{\partial K_a^2}[\beta\frac{\partial q}{\partial K_p}(\frac{\partial k}{\partial K_d})^2 - (\frac{\partial s}{\partial K_p} + k\beta\frac{\partial q}{\partial K_p})\frac{\partial^2 k}{\partial K_d^2}]}{\Delta} \begin{matrix} > \\ = 0 \\ < \end{matrix} \tag{17a}$$

$$\frac{dK_a}{dP^T} = -\frac{\frac{\partial h}{\partial K_a}}{P^T\frac{\partial^2 h}{\partial {K_a}^2}} > 0 \tag{17b}$$

$$\frac{dK_d}{dP^T} = \frac{\frac{\partial k}{\partial K_d}\{q[(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T\frac{\partial^2 s}{\partial K_p^2}] + P^T\frac{\partial q}{\partial K_p}(\frac{\partial s}{\partial K_p} + k\beta\frac{\partial q}{\partial K_p})\}}{-P^T\{q\frac{\partial^2 k}{\partial {K_d}^2}[(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T\frac{\partial^2 s}{\partial K_p^2}] + P^T\beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2\}} \begin{matrix} > \\ = 0 \\ < \end{matrix} \tag{17c}$$

According to the results of the above, thus:

Proposition 3. *The effects of* P^T *change to* K_p *and* K_d *are ambiguous, however, if allowance price (*P^T*) is high enough (i.e.* $P^T\beta = P$*), then the effects are definitely positive.*

Due to allowance price is the opportunity cost of emissions, and increase P^T will increase benefits of environmental capitals (K_d) investment, however, need to cost as well. Therefore, how to change of K_d can't be determined in advance. Unless, P^T is high enough, i.e. $P^T \beta = P$, thus, benefit effect definite greater than cost effect, then induce more invest K_d, which indicates equation (17c) will positive (proof see appendix B). In addition to, abound environmental capital can offset higher emission of the firm, which means in the emission cap system, firm is able to afford more K_p (seeing (17b)). The policy implication shows if allowance market activity enough (higher P^T), which will encourage to increase more K_p investments and get the win-win strategy.

In order to discuss the environmental performance effect of PLCETM, total differential life cycle emissions function, including e_p and e_d, and substitute them into equation (16a), (16b) and (16c), and let $R_p = v_p(\delta_p + r)$, $R_a = v_a(\delta_a + r)$, $R_d = v_d(\delta_d + r)$, which are rental prices of K_p, K_a and K_d respectively.

$$\begin{aligned}\frac{de_p}{dP^T}+\frac{de_d}{dP^T} &= \frac{ds}{dK_p}\frac{dK_p}{dP^T}-\frac{dh}{dK_a}\frac{dK_a}{dP^T}+\beta q\frac{dk}{dK_d}\frac{dK_d}{dP^T}+\beta k\frac{dq}{dK_p}\frac{dK_p}{dP^T}\\ &= (\frac{ds}{dK_p}+\beta k\frac{dq}{dK_p})\frac{dK_p}{dP^T}+\beta q\frac{dk}{dK_d}\frac{dK_d}{dP^T}-\frac{dh}{dK_a}\frac{dK_a}{dP^T}\\ &= \frac{1}{P^T}\{(P\frac{dq}{dK_p}-R_p)\frac{dK_p}{dP^T}-R_a\frac{dK_a}{dP^T}-R_d\frac{dK_d}{dP^T})\} \lessgtr 0\end{aligned} \tag{18}$$

From equation (18), effect of P^T change to life cycle total emissions is ambiguous, depends on many factors, however, if both of R_a and R_d are high enough and can greater than the net marginal values of K_p ($P\frac{\partial q}{\partial K_p} - R_p > 0$, seeing equation (18)), yield opposite effect of allowance price change to life cycle emissions, which means that if both of rental prices of K_a and K_d are high enough, correspondence with higher capital quality(or productivity) of K_a and K_d, means that in the efficiency emission trading market, creating higher allowance price, can reach both of the purpose of economic growth and environmental improvement. It also illustrate why government usually like to use the financial incentive instruments, such as tax credit or accelerate depreciation, to promote firm upgrade the newest equipments.

Proposition 4. *If the rental price of both* K_a *and* K_d *high enough, that is the necessary condition of the opposite effect of allowance price change to life cycle emissions.*

Since β reflects various degree of pollution among the firms, the effects of emission intensives change show as follows (proof see appendix A):

$$\frac{dK_p}{d\beta} = \frac{{P^T}^3 q\beta \frac{\partial q}{\partial K_p}\frac{\partial^2 h}{\partial {K_a}^2}[(\frac{\partial k}{\partial K_d})^2 - k\frac{\partial^2 k}{\partial K_d^2}]}{\Delta} > 0 \tag{19a}$$

$$\frac{dK_a}{d\beta} = 0 \tag{19b}$$

$$\frac{dK_d}{d\beta} = \frac{\frac{\partial k}{\partial K_d}\{q[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T \frac{\partial^2 s}{\partial K_p^2}] + P^T k\beta(\frac{\partial q}{\partial K_p})^2\}}{-\beta\{q\frac{\partial^2 k}{\partial {K_d}^2}[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T \frac{\partial^2 s}{\partial K_p^2}] + P^T\beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2\}} > 0 \tag{19c}$$

Proposition 5. *Increasing emission intensives will result in increased investment of* K_p *and* K_d*, but not change the* K_a *investment level.*

As a result, raising β will increase opportunity cost of the off-site emissions (e_d), therefore, induce firms more K_d investment (see equation (19c)), which will offset partial life cycle emissions of products, under life cycle emissions cap policy, which provide the possibility of more emission on-site to the firms, affording more invest K_p potential of the firms to usage additional emission allowance, indicating that even exist more dirty process(higher β), still may achieve the purpose both economic growth and environmental protection.

Bovea and Vidal (2004) show that product value can be increased with the use of a design that reduces simultaneously the environmental impact and external costs, besides, increase consumer's preference of the green products and willing to pay (WTP). To consider the effect of the green product to consumer's WTP, this paper endogenous prices of the products, $P = P(k)$, and let $\partial P / \partial k < 0$ which corresponds with more cleaner products will raise demand price of consumers. Thus,

$$q(\frac{\partial P}{\partial k} - P^{T}\beta)\frac{\partial k}{\partial K_d} = v_d(\delta_d + r) \quad (20)$$

Comparing with equation (20) and (16c), we find that to incorporate the price effect of the greener product will increase marginal benefit of K_d (see left side of equation (20)), and facilitate to more invest K_d of the firms. Policy implication of the above analysis, which denotes government should promote environmental educations, strength awareness of the public, and increase market value of the greener products result in economic incentive of the environmental friendly production. Besides, the government also can uses eco-labeling system and mixed with green procurement mechanism, creates market demand of green products to achieve the purpose of the deployment green production.

Result 5: *Using both of eco-labeling and green procurement mechanism could provide good information to the consumer, besides, promote the consumer's preference and create the green products market demand, then encourage more environmental friendly investment.*

4. Conclusion

In the proposed concept for trading PLC emission rights would be motivated by economic incentives to take an increased responsibility for information flow and initiatives for product improvements. EPR is key role to the IPP, and how to strength ERP effectiveness to achieve green consuming and production behavior is the most important policies and measures of the countries to pursuit sustainable development.

The paper pioneering introduces two economic incentive models, PLCEFM and PLCETM, to describe the efficiency of the EPR policy. The results of the research are as following: (1) adopts discrimination rate to final waste disposal is more effectiveness in encourage environmentally friendly designing by the firm; (2) if the price of the emission allowance is high enough, it facilitate green production by the firm; (3) if consumers increase their preference to the green products that can promote environmental design of the product by the firm; (4) if the rental price of abatement and environmentally friendly capital is high enough, then the trading allowance of PLC will improve environmental performance.

Although this paper has comprehensively discussed the environmental effects of various economic incentive instruments in the EPR system, there are some issues for continuous study in the future, such as endogenous allowance price and introducing green procurement into the model.

Appendix A

To discuss comparative static, total differential equation (16a), (16b) and (16c) as follows:

$$[(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p{}^2}-P^T\frac{\partial^2 s}{\partial K_p{}^2}]dK_p - P^T\beta\frac{\partial q}{\partial K_p}\frac{\partial k}{\partial K_d}dK_d$$
$$=(\frac{\partial s}{\partial K_p}+k\beta\frac{\partial q}{\partial K_p})dP^T-\frac{\partial q}{\partial K_p}dP+P^T k\frac{\partial q}{\partial K_p}d\beta+(\delta_p+r)dv_p+v_p(d\delta_p+dr) \quad \text{(A1)}$$

$$P^T\frac{\partial^2 h}{\partial K_a^2}dK_a=-\frac{\partial h}{\partial K_a}dP^T+(\delta_a+r)dv_a+v_a(d\delta_a+dr) \quad \text{(A2)}$$

$$-P^T\beta\frac{\partial q}{\partial K_p}\frac{\partial k}{\partial K_d}dK_p-P^T q\beta\frac{\partial^2 k}{\partial K_d^2}dK_d$$
$$=q\beta\frac{\partial k}{\partial K_d}dP^T+P^T q\frac{\partial k}{\partial K_d}d\beta+(\delta_d+r)dv_d+v_d(d\delta_d+dr) \quad \text{(A3)}$$

According to the sufficient condition, requiring Hessian Matrix must satisfy: $\Delta=-P^{T^2}\beta\frac{\partial^2 h}{\partial K_a^2}\{q\frac{\partial^2 k}{\partial K_d^2}[(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p^2}-P^T\frac{\partial^2 s}{\partial K_p^2}]+P^T\beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2\}<0$, and $\frac{\partial^2 h}{\partial K_a^2}<0$, $\frac{\partial^2 k}{\partial K_d^2}>0$, then obtains $(P-P^T k\beta)\frac{\partial^2 q}{\partial K_p{}^2}-P^T\frac{\partial^2 s}{\partial K_p{}^2}<0$. Furthermore, using Cramer's rule to solve the above simultaneous equations, thus:

1. Tradable permits price (P^T) change

Letting $dP=d\beta=dv_p=dv_a=dv_d=d\delta_p=d\delta_a=d\delta_d=dr=0$.

$$\frac{dK_p}{dP^T}=\frac{P^{T^2}q\beta\frac{\partial^2 h}{\partial K_a{}^2}[\beta\frac{\partial q}{\partial K_p}(\frac{\partial k}{\partial K_d})^2-(\frac{\partial s}{\partial K_p}+k\beta\frac{\partial q}{\partial K_p})\frac{\partial^2 k}{\partial K_d^2}]}{\Delta}\ \begin{matrix}>\\=0\\<\end{matrix} \quad \text{(A4)}$$

$$\frac{dK_a}{dP^T}=-\frac{\frac{\partial h}{\partial K_a}}{P^T\frac{\partial^2 h}{\partial K_a{}^2}}>0 \quad \text{(A5)}$$

$$\frac{dK_d}{dP^T}=\frac{P^T\beta\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial k}{\partial K_d}\{q[(P-P^Tk\beta)\frac{\partial^2 q}{\partial K_p^2}-P^T\frac{\partial^2 s}{\partial K_p^2}]+P^T\frac{\partial q}{\partial K_p}(\frac{\partial s}{\partial K_p}+k\beta\frac{\partial q}{\partial K_p})\}}{\Delta}\begin{matrix}>\\=0\\<\end{matrix}$$

(A6)

The sign of equation (A5) is definite positive, however, equation (A4) and (A6) can't determine its sign in advance.

2. Products price (P) change

Letting $dP^T=d\beta=dv_p=dv_a=dv_d=d\delta_p=d\delta_a=d\delta_d=dr=0$.

$$\frac{dK_p}{dP}=\frac{P^{T^2}q\beta\frac{\partial q}{\partial K_p}\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial^2 k}{\partial K_d{}^2}}{\Delta}>0 \qquad \text{(A7)}$$

$$\frac{dK_a}{dP}=0 \qquad \text{(A8)}$$

$$\frac{dK_d}{dP}=\frac{-P^{T^2}\beta(\frac{\partial q}{\partial K_p})^2\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial k}{\partial K_d}}{\Delta}>0 \qquad \text{(A9)}$$

Both of the sign of equation (A7) and (A9) are definite positive, however, K_a is independent of P.

3. Emission intensive (β) change

Letting $dP=dP^T=dv_p=dv_a=dv_d=d\delta_p=d\delta_a=d\delta_d=dr=0$.

$$\frac{dK_p}{d\beta}=\frac{P^{T^3}q\beta\frac{\partial q}{\partial K_p}\frac{\partial^2 h}{\partial K_a{}^2}[(\frac{\partial k}{\partial K_d})^2-k\frac{\partial^2 k}{\partial K_d^2}]}{\Delta}>0 \qquad \text{(A10)}$$

$$\frac{dK_a}{d\beta}=0 \qquad \text{(A11)}$$

$$\frac{dK_d}{d\beta}=\frac{\frac{\partial k}{\partial K_d}\{q[(P-P^Tk\beta)\frac{\partial^2 q}{\partial K_p^2}-P^T\frac{\partial^2 s}{\partial K_p^2}]+P^Tk\beta(\frac{\partial q}{\partial K_p})^2\}}{-\beta\{q\frac{\partial^2 k}{\partial K_d{}^2}[(P-P^Tk\beta)\frac{\partial^2 q}{\partial K_p^2}-P^T\frac{\partial^2 s}{\partial K_p^2}]+P^T\beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2\}}>0 \qquad \text{(A12)}$$

Both of the sign of equation (A10) and (A12) are definite positive, however, K_a is independent of β.

4. Price of $K_p\,(v_p)$ change

Letting $dP = dP^T = d\beta = dv_a = dv_d = d\delta_p = d\delta_a = d\delta_d = dr = 0$

$$\frac{dK_p}{dv_p} = \frac{-P^{T^2} q\beta(\delta_p + r)\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial^2 k}{\partial K_d{}^2}}{\Delta} < 0 \tag{A13}$$

$$\frac{dK_a}{dv_p} = 0 \tag{A14}$$

$$\frac{dK_d}{dv_p} = \frac{P^{T^2}\beta(\delta_p + r)\frac{\partial q}{\partial K_p}\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial k}{\partial K_d}}{\Delta} < 0 \tag{A15}$$

Both of the sign of equation (A13) and (A15) are definite negative, however, K_a is independent of v_p.

5. Depreciation rate of K_p (δ_p) change

Letting $dP = dP^T = d\beta = dv_p = dv_a = dv_d = d\delta_a = d\delta_d = dr = 0$

$$\frac{dK_p}{d\delta_p} = \frac{-P^{T^2} q\beta v_p \frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial^2 k}{\partial K_d{}^2}}{\Delta} < 0 \tag{A16}$$

$$\frac{dK_a}{d\delta_p} = 0 \tag{A17}$$

$$\frac{dK_d}{d\delta_p} = \frac{P^{T^2}\beta v_p \frac{\partial q}{\partial K_p}\frac{\partial^2 h}{\partial K_a{}^2}\frac{\partial k}{\partial K_d}}{\Delta} < 0 \tag{A18}$$

Both of the sign of equation (A16) and (A18) are definite negative, however, K_a is independent of δ_p.

6. Interest rate (r) change

Letting $dP = dP^T = d\beta = dv_p = dv_a = dv_d = d\delta_p = d\delta_a = d\delta_d = 0$

$$\frac{dK_p}{dr} = \frac{P^{T^2}\beta\frac{\partial^2 h}{\partial K_a{}^2}\left(v_d\frac{\partial q}{\partial K_p}\frac{\partial k}{\partial K_d} - qv_p\frac{\partial^2 k}{\partial K_d{}^2}\right)}{\Delta} < 0 \tag{A19}$$

$$\frac{dK_a}{dr} = \frac{v_a}{P^T \frac{\partial^2 h}{\partial K_a{}^2}} < 0 \tag{A20}$$

$$\frac{dK_d}{dr} = \frac{P^T \frac{\partial^2 h}{\partial K_a{}^2}\{v_d[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p{}^2} - P^T \frac{\partial^2 s}{\partial K_p{}^2}] + P^T \beta v_p \frac{\partial q}{\partial K_p}\frac{\partial k}{\partial K_d}\}}{\Delta} < 0 \tag{A21}$$

All of the above three equations are opposite sign.

Table A1 results of comparative static analysis

Exogenous Variables	K_p	K_a	K_d
P^T	?	+	?
P	+	0	+
β	+	0	+
v_p	–	0	–
v_a	0	–	0
v_d	–	0	–
δ_p	–	0	–
δ_a	0	–	0
δ_d	–	0	–
r	–	–	–

"+" denote two variables will change by the same way.
"-" denote two variables will change by the opposite way.
"0" denote two variables have no relation.
"?" denote the relation is uncertain between two variables.

Appendix B

Denominator of equation (17a) is negative ($\Delta < 0$) and $\partial^2 h / \partial K_a^2 < 0$, so its sign is determined by:

$$P^T \beta \frac{\partial q}{\partial K_p}(\frac{\partial k}{\partial K_d})^2 - P^T(\frac{\partial s}{\partial K_p} + k\beta \frac{\partial q}{\partial K_p})\frac{\partial^2 k}{\partial K_d^2} \tag{B1}$$

If $(\frac{\partial k}{\partial K_d})^2 > \frac{\partial^2 k}{\partial K_d^2} > 0$, then the sign of (B1) is decided by:

$$P^T \beta \frac{\partial q}{\partial K_p} - P^T(\frac{\partial s}{\partial K_p} + k\beta \frac{\partial q}{\partial K_p}) \tag{B2}$$

Rewriting equation (16a) as follows:

$$P \frac{\partial q}{\partial K_p} - P^T(\frac{\partial s}{\partial K_p} + k\beta \frac{\partial q}{\partial K_p}) = v_p(\delta_p + r) > 0 \tag{B3}$$

From the equation (B3), we can find that if price of emission allowance is high enough, i.e. $P^T \beta = P$, then both of the sign of equation (B1) and (17a) are positive. Due to the denominator of equation (17c) is positive and $\partial k / \partial K_d < 0$, so its sign is decided by:

$$q[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T \frac{\partial^2 s}{\partial K_p^2}] + P^T \frac{\partial q}{\partial K_p}(\frac{\partial s}{\partial K_p} + k\beta \frac{\partial q}{\partial K_p}) \tag{B4}$$

If we multiply $\frac{\partial^2 k}{\partial {K_d}^2}$ (>0) to the equation (17c)(>0), and rewrite equation (B4) yields:

$$q \frac{\partial^2 k}{\partial {K_d}^2}[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p^2} - P^T \frac{\partial^2 s}{\partial K_p^2}] + P^T \frac{\partial q}{\partial K_p}\frac{\partial^2 k}{\partial {K_d}^2}(\frac{\partial s}{\partial K_p} + k\beta \frac{\partial q}{\partial K_p}).$$

Since $q \frac{\partial^2 k}{\partial {K_d}^2}[(P - P^T k\beta)\frac{\partial^2 q}{\partial K_p^2}) - P^T \frac{\partial^2 s}{\partial K_p^2}] + P^T \beta(\frac{\partial q}{\partial K_p})^2(\frac{\partial k}{\partial K_d})^2 < 0$, then the way to judge the sign of equation (B4) is the same with equation (17a), in other word, if $P^T \beta = P$, then its sign is positive.

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