Efficiency Comparison between Output Tax and Emission Tax as an Environmental Tax*

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과세형태에 따른 환경세의 조세효율성 비교: 산출물과세 vs. 배출세

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국 문 요 약

환경세의 조세효율성과 관련된 기존의 연구들은 대부분 소비세 형태의 환경세를 가정하고 있다. 즉 환경세가 최종산출물의 소비과정, 또는 생산과정에 투입되는 중간재 소비에 부과됨을 가정하는 것이다. 이는 암묵적으로 오염발생재의 소비가 오염자체와 상당히 밀접한 관계에 있음을 전제로 하는 것으로 보인다. 하지만 현실적으로 오염발생재의 소비와 여기에서 발생되는 오염자체는 동일하지 않기 때문에 이러한 가정은 현실을 왜곡할 가능성이 높다.

본 논문에서 환경세를 오염발생재의 소비에 부과되는 형태와 오염배출에 직접부과되는 형태로 구분하고, 과세형태에 따른 조세효율성을 계산적 일반균형시뮬레이션(computational general equilibrium simulation) 분석을 통해 비교해 보았다. 시뮬레이션 분석결과에 따르면 오염배출에 직접 과세되는 형태, 즉 배출세 형태의 환경세가 조세효율성 측면에서는 더욱 우수한 것으로 나타났다. 아울러 이와 같은 결과는 효용함수에 대한 동조성(homotheticity) 가정의 적용여부와는 무관한 것으로 분석되었다. 즉 시장왜곡적인 조세가 이미 도입되어 있는 경우, 세수중립적인 환경세의 조세효율성 개선효과는 효용함수의 동조성 가정여부에 따라 민감한 것으로 나타나지만, 조세효율성은 산출물의 소비에 부과되는 형태보다 배출세 형태의 환경세가 더 우수한 것으로 나타났다.

주제어 환경세 정책, 일반균형분석, 조세효율성, 산출물과세, 배출세

Abstract

Existing researches on tax efficiency of environmental taxes mostly focuses on taxes imposed on the consumption process of the final output, or goods that create pollution during the input process of intermediate goods. The assumption here is that there is a significant relation between the consumption of polluting goods and the pollution itself. However, in reality they are not identical. This signifies that the above assumption may distort the actual results.

This study classifies environmental tax into two different forms, output tax and emission tax. The

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former is the tax that is imposed on the consumption of polluting goods, while the latter is directly levied onto the emission of pollution. It then compares the efficiency of these taxes through the computational general equilibrium simulations. After analyzing the simulation, it was proven that the direct imposition on pollution, or environmental tax as emission tax, was more effective in terms of tax efficiency. Furthermore, these results were revealed as irrelevant to the assumption of homotheticity in utility function. Thus, if market distortionary tax already exist, then the effectiveness of revenue neutral environmental tax reform will be sensitive to the assumption of homotheticity for utility function. However, environmental taxes as emission taxes have been shown to be more effective in tax efficiency than output taxes.

Keywords Environmental tax policy, General equilibrium analysis, Tax efficiency, Output tax, Emission tax

Ⅰ. Introduction

As the issue of global warming emerges, nations are adopting various and systematic environmental policies to protect the environment, particularly, seeking cost efficient alternatives that utilize market mechanism. Out of all these policies, the environmental tax, which is already making visible progress in environmentally well developed areas such as Northern Europe, is the most actively discussed of them all. Recently, Korea has also proclaimed sustainable green growth as one of the major policy objectives and proposed to adopt various policies including environmental tax. As per the example of other developed nations, environmental taxes has demonstrated efficiency in environment protection by reducing the pollution, and is acknowledged to be one of the vital environmental policies due to its superiority of cost effectiveness.

Thanks to its practicality, the environmental tax policy is vigorously extending its scope of discussion, for example: the Double Dividend Hypothesis. Discussion over Double Dividend Hypothesis focuses on the non-environmental effect of environmental tax, which not only seeks qualitative improvement of the environment through the revenue neutral environmental tax reform, but also on the efficiency gain in the overall tax system. This debate has begun in the 1990s and continued throughout the 2000s, which was considered to be a substantial research achievement. The focus of recent debates on this hypothesis has moved on from simply discussing the possibility of attaining it, and has extended to other subjects, such as conditions and assumptions to realize the hypothesis[1].

Optimal environmental tax rate is another topic which is frequently discussed with environmental taxes. Debate on this topic is based on the traditional Pigouvian tax theory, which suggests that the optimal environmental tax rate should be configured in accordance to the marginal environmental damage. Nonetheless, since it assumes a situation of partial equilibrium, in which the pre-existing market distortionary tax does not exist, it has its limits of being inapplicable in the real world economy. The debate on optimal environmental tax has been built on this theoretical perception, which continues on to discussions of various situations and changes in the assumptions.

However, the discussions on the form of the taxation of environmental tax have been relatively inactive. Like some initial research has indicated, environmental taxes have a wide variety in the effectiveness depending on how it will be imposed, yet there has been not enough discussion on that factor. Theoretically, the effectiveness of the environmental tax policy differs according to the proximity to the pollutant. Thus, by imposing it closer to the pollutant, the reduction in pollution will become greater[2]. This is not unlike what the Pigouvian tax theory, the cornerstone of the environmental taxes, claims. In other words, the Pigouvian tax as an environmental tax should be imposed on the pollutant itself. From this aspect, it is difficult to say that the recently introduced environmental tax is following the key idea of the Pigouvian tax closely.

Almost all research regarding environmental taxes follow the assumption of the tax levy on goods that emits pollution in the process of consumption in the final product (or in the process of being used in the form of intermediate goods). This can be interpreted to mean that an intricate relationship exists between the consumption of polluting goods and pollution. Therefore, under the assumption that the consumption of polluting goods creates pollution, environmental taxes are applied as levying taxes to the consumption of pollutants rather than on the pollution itself. While this may seem like a feasible

1) Refer to Kim(2009, 2011) for the general discussion on the Double Dividend Hypothesis.

2) Specific details will be discussed in Chapter II.

assumption, unless the relation of consumption of polluting goods and emission correlates, imposing taxes on pollutants is not a true environmental tax as acknowledged by the Pigouvian tax theory. From this standpoint, the goal of the tax levy should not be simply the consumption of polluting goods, but also the analysis of the pollution itself.

The purpose of this study is to analyze and compare the efficiency across different forms of environmental tax. In other words, it focuses on the comparison of the tax efficiency between the output tax on consumption of polluting goods and the emission tax on pollution itself. That is to say, this research will classify environmental tax into the output tax, which is widely applied in relevant researches, and the emission tax form, which taxes on the pollution itself. In order to reach the policy implications, this study will set up models of two different types of tax systems in a perspective of general equilibrium, and compare the tax efficiency of different types of taxation through a small scale, simple computational general equilibrium (CGE) simulation.

The composition of this study is as follows. Chapter Ⅱ will review previously relevant researches and deduct additional discussion points derived from them. Chapter Ⅲ will set up a simple static general equilibrium model and observe the changes of tax efficiency by adopting different form of environmental tax. Interpretation of the analyzed results and deriving policy implications will be dealt with in the conclusion.

Ⅱ. Review on Previous Studies

There are not many of studies that sort environmental tax according to the form of taxation, i.e. output tax or emissions tax, and analyze their effectiveness. Previous studies on the tax efficiency of various forms of tax levies are even more limited. This not only results from the characteristics of environmental tax as a policy method, but also from the fact that theoretical discussions related to environmental tax have been eventuated only very recently. It is well known that environmental tax is a policy method that has the objective of ‘qualitative enhancement of the environment through restraining the occurrence of pollution.’ Therefore, initial discussions could not be dispersed to topics other than the effect of environmental tax and whether to introduce it. Consequently, the initial focus of environmental tax was mostly on either 'the improvement of the environmental quality as an effect of environmental tax' or on 'the period to introduce the environmental tax'. Debates relevant to tax efficiency of environmental tax have accelerated through instigations of theoretical discussions of environmental taxes' non-environmental effects, such as the feasibility of the Double Dividend Hypothesis and determining the optimal environmental tax rate under the general equilibrium situation. From this perspective, it is natural that there is not yet a sufficient amount of research on the comparison of effectiveness by the form of tax or tax efficiency.

The preliminary discussions on the form of environmental tax and effectiveness of it have been raised by Oates (1995). According to Oates, environmental taxes should be designed to correspond as closely as possible to pollution itself. In other words, as environmental taxes come closer to the sources of emission, the tax efficiency will become higher. The research that classifies environmental taxes to output taxes as a figure of consumption tax and emission tax on the pollutant can be found in Cropper and Oates (1992). It indicates the side effects of environmental tax levied in two different forms, and explains the effectiveness of tax policy through comparing them. Specifically, if environmental taxes improperly target the pollutant, output taxes may result in a loss of value in output, while adopting environmental tax as an emission tax needs a substantial scale of monitoring cost for appropriate operation of the system. In short, environmental taxes implemented as output taxes may result in the loss of output, and monitoring costs occur when they are applied as an emission taxes. The research concludes that when such a trade-off exists, taxing on the output is superior to that of the emission.

The result of the research has been reconfirmed by Schmutzler and Goulder (1997). They pointed out that if the monitoring of pollution is incomplete, output taxes creates a loss of output, yet it is still more effective than emissions taxes, which requires a lot of monitoring costs, thus asserting that output tax is more efficient than emission tax. From society's point of view as a whole, the side effects that occurs from the massive amount of monitoring costs stemming from emission taxes, is by far greater than that of output taxes, or loss of value in output.

Meanwhile Eskeland and Devarajan (1996) have approached the method of environmental policy by dividing them to direct and indirect instruments. They emphasize the validity of direct instruments in that environmental tax as a political tool to control the environmental externality is a tax that should directly targets the pollutant. In addition, Eskeland and Devarajan pointed out that although direct tax on the source of pollution is preferable, it may not be feasible due to limitations in real world economy. For instance, environmental taxes as emissions taxes face the constraint of the issue of observing and monitoring the pollution, costs, and administrative as well as technical limitations in taxation.

Cremer and Ghavari (1999) estimate the optimal environmental tax rate when pollution impacts various inputs for production. They pointed out that the environmental tax rate should be estimated separately by each target, since pollution affects each input differently. Also, they argue that the environmental tax should be classified into output and emission taxes, followed by the type and characteristics of the transpired pollution.

Fullerton *et. al.* (2001) contains comprehensive subjects and analyses relevant to forms of environmental tax. It states that the target should be hit first for environmental tax to be effective enough as a policy tool to control the externality. This indicates that environmental taxes may have a positive impact on the consumer's welfare when it is closely levied to the pollutant, which corresponds to Oates (1992). Furthermore, there are more environmental taxes as output taxes than emission taxes when observing each nation where environmental taxes have already been adopted. The study seeks rationale from technical problems related to measuring pollution and excessive monitoring cost. That is, emission taxes are more effective in controlling pollution in terms of policy effectiveness. However, constraints exist due to predicaments such as monitoring costs. Meanwhile, Fullerton *et. al.* classifies environmental taxes as output taxes and emission taxes, and provides analyses of the effect that it has on the consumer's welfare for each type, through general equilibrium analysis. According to the results, emission taxes proved to be more effective than output taxes; and consumer welfare could be raised by approximately two times its original. This conclusion differs from precedential studies, such as Cropper and Oates (1992), Schmutzler and Goulder (1997). Evidently, these assertions may not seem completely contradictory because their assumptions and premises are different. Nonetheless, while earlier studies emphasize the effectiveness of output taxes, recent ones take notice of the effectiveness of emission taxes, thus it cannot be said that the results of each research is similar.

As previously examined, most of the existing environmental tax policies do not have specific distinctions between emission taxes and output taxes (in the form of consumption taxes). This may be due to technical limitations or convenience in taxation, but also because of the tacit assumption that theoretically the consumptions of pollutant have a functional correspondence with emission. However, consumption of polluting goods does not necessarily imply perfect pollution, and various amounts and quality of pollution can occur as conditions of consumption changes. In other words, there exists a difference in quality of the occurred pollution in reality. From this point of view, the hypothesis that there is a relationship between 'consumption' and 'emission' is a very strong assumption, which may distort reality. Nevertheless, verified from previous research that took an approach to distinguish the form of tax, clearly determining which of them is more effective is still disputable. Hence, this study will compare the tax efficiency of two different forms of taxation, particularly, apply output and emission tax into the general equilibrium analysis model and compare the tax efficiency according to the policy change.

Ⅲ. Model and Simulation

1. Model

The simulation model will measure the tax efficiency of each form of environmental tax, through the optimization process of the representative consumer and producer. Accordingly, this study will refer to the model of Ballard *et. al.* (2005), which is popularly used in many tax efficiency analysis. Since the focus of this analysis is on the optimal behavior of the producer as well as the consumer, following the change of taxation form, thus the model should be extended to catch the producer's behavioral change in the context of general equilibrium.

The model of Ballard *et. al.* assumes that the representative consumer acquires utility from consumption of leisure, and consumption of goods that create pollution and goods that does not. In the model, the utility take a form of 'nested CES' type function,' frequently used in microeconomic behavior analysis models which are compatible with the assumptions of homotheticity and separability[3]. So in this model the representative consumer can obtain utility from the consumption of leisure (l) and composite goods (Q), which is consist of goods that generate pollution (D) and goods that does not (C). In addition, utility is affected by the quality of the environment (E) and the supply level of public goods (G). This is shown in the following implicit function.

$$U = U\{G, E, H(l; Q(C, D))\} \qquad (1)$$

Since we consider experiments in which public expenditure is held constant, we can enter G additively without loss of generality. And the environmental quality in equation (1) is the function of consumption of polluting goods, and if assumed that E decreases as consumption of polluting goods increases ($\frac{\partial E}{\partial D} < 0$), equation (1) can be expressed as the following:

$$U = H(l; Q(C, D)) + \Pi D + G \qquad (1')$$

The $\pi(\pi<0)$ is the environment externality that 1 unit of polluting goods consumption create, which is Marginal Environmental Damage.

According to equation (1) and (1'), the consumer's utility function $U(\cdot)$ is consisted of outer nest $H(\cdot)$ and innermost nest $Q(\cdot)$ as a sub-utility function. In this case, the

3) The separability means that the consumer's choice of leisure/labor is separable from the choice between goods *C* and goods *D*. So, in this context, the separability implies '*weak separability*'. For detailed explanation, refer to Sandmo (1975).

consumer goes through 2-stage budgeting, with the first stage deciding leisure and composite consumption goods, and the second stage deciding the consumption level of *C* and *D* goods, which constitutes the composite consumption.

In order to conduct simulation analysis, the utility function needs to be more specified, in which key assumptions of environmental tax are applied in the model of Ballard *et. al.*[4] The outer nest *H(·) of equation (1') may be expressed as the following:*

$$H = [\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} Q^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \qquad (2)$$

Equation(2) is in the form of constant elasticity of substitution(CES) function, σ being the elasticity of substitution between leisure(*l*) and composite consumption goods, and β as the weight of the utility function of leisure. *Q* in equation (3) is the good made up of polluting goods *D* and non-polluting goods *C*. The decision of composite goods consumption determines the amount of consumption of good *C* and *D*, which forms the innermost nest of the utility function.

$$Q = [\alpha^{\frac{1}{\nu}} (D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} (C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{\nu}{\nu-1}} \qquad (3)$$

*D** and *C** in sub-utility function (3) indicates the minimum requirement of consumption of polluting goods *D* and non-polluting good *C*[5]. When granting this to each consumption goods, the homotheticity and non-homotheticity of the utility function can be simply configured through the modification of the minimum requirement of consumption[6]. The α and ν are the parameters that indicate the consumption weight and

4) Refer to Kim (2011) for specific contents.

5) When setting the minimum requirement of consumption to 0 ($D^*=C^*=0$), equation (3) represents a homothetic utility function, in which also has homotheticity to the origin. If the minimum requirement of consumption is not 0 ($D^*\neq0$, $C^*\neq0$), equation (3) is non-homothetic to origin, but homothetic to displaced origin. Due to this trait, equation (3) is defined as the Generalized Constant Elasticity of Substitution (GCES) function.

6) The non-homohtheticity of utility function is significant to the validity of the double dividend hypothesis, which is recently being discussed actively. Previous studies have shown when assuming that utility function is non-

the elasticity of substitution of polluting goods.

Meanwhile, the production function used in Ballard *et. al.* is a simple linear function producing only through labor as an input. The equation for production is as follows:

$$D = A_D L_D \tag{4}$$

$$C = A_C L_C \tag{5}$$

L_D, L_C in equation(4) and (5) represent the input of labor used to produce final consumption goods D and C. A_C and A_D are scale parameters of the production function.

In order to measure the tax efficiency of the implementation of environment tax policy, an assumption on the initial tax system prior to the environmental tax reform is required. As in Ballard *et. al.*, this study assumes that the labor income tax is the only pre-existing market-distortionary one in the initial tax system. This assumption is expressed through the equation for the consumer's budget constraint below.

$$w'T = P_Q Q + w'l + \Gamma \tag{6}$$

On the equation above, T is the time endowment which the consumer is able to put into labor(L) and leisure(l), hence $T=L+l$ can be established between the leisure and labor. w' represents the net of labor income tax(t_L) wage rate, therefore, the equation $w'=w(l-t_L)$ holds for pretax wage(w) and after-tax wage(w'). Γ is the value of minimum required level of consumption. P_Q is the price of the composite consumption goods and functional form of it is as follows[7]:

$$P_Q = \left[\alpha P'^{(1-\nu)}_D + (1-\alpha) P'^{(1-\nu)}_C\right]^{\frac{1}{(1-\nu)}} \tag{7}$$

homothetic, revenue neutral environmental tax reform, policy may trigger improvements in tax efficiency. Refer to Kim(2002), Ballard, Goddeeris, and Kim(2005) for further discussion.

7) Derivation of equation (7) can be found in the appendix.

Assume that t_D and t_C are the taxes on the each goods' consumption, P'_D, P'_C in equation(7) represent the net of tax price of goods *D* and *C* respectively, so the equations $P'_D=P_D(1+t_D)$ and $P'_C=P_C(1+t_C)$ hold for before and after tax prices. In this context, t_D is the environmental tax on the consumption of output in goods D.

The model of Ballard *et. al.* analyzes the effect of the tax switch, from labor income tax to environment tax, on the gain in tax efficiency. In other words, the model takes effect when environment tax is imposed in the form of consumption tax. However, since the objective of this research is to analyze the difference in the tax efficiency when tax is levied in the emission tax form, there needs to be additional analysis on the producer side as well. Thus, this study will also include the producer's behavioral change in the case that environmental tax is levied as emission tax, namely adjustment in emission. When setting the optimization of producers to modification of emission for minimizing the costs, producer's problem due to the levy of emission tax can be defined as follows:

$$Min.\ t_E D(EM+\Delta EM)+\Psi(-\Delta EM, D) \tag{8}$$

In equation(8), t_E is defined as the tax levied for pollutant emission, i.e, emission tax, and *EM* is the emission per one unit of production in polluting good *D*. ΔEM is the pollution change per unit of production, in which $0 \le \left|\frac{\Delta \mathrm{EM}}{\mathrm{EM}}\right| \le 1$ is always valid. Additionally, Ψ is the implicit cost function of pollution abatement. Therefore equation (8) consists of the tax payment cost and pollution abatement cost. According to equation (8), the tax payment of producer is reduced either when the amount of final product is reduced, or when the pollution is prevented. This clearly exhibits the reality of pollution cost management. The pollution abatement cost function of the producer Ψ can be expressed as the following:

$$\Psi = D_\mu(-\Delta EM)^\theta \tag{9}$$

μ and θ in equation(9) is each defined as the scale parameter and its exponent of the cost function of pollution abatement. In order to get the most accurate analysis, the cost function of pollution abatement is assumed as a well behaved convex function. Thus, θ is greater than 1.

In an effort to solve the producer problem, solving equation (8) for level of abatement will result in the following the first order condition.

$$t_E D = \frac{d\Psi}{d\Delta EM} \qquad (10)$$

Equation (10) indicates the cost minimization relevant to management of pollution. That is, to obtain the optimum pollution level that minimizes production cost, the marginal benefit ($t_E D$) from pollution abatement should be equal to marginal cost of the abatement.

2. Policy Simulation

Policy changes in simulation, like other similar previous researches, switch the pre-existing labor income tax to environmental tax. In order to measure the double dividend effect from the tax reform, the tax revenue of the government has been set as a constant. Prior to the environmental tax policy, the government imposes 40% of labor income tax. Environmental tax is levied on the consumption of polluting goods *D*, while non-polluting *C* goods is untaxed. The parameters that greatly impact the simulation result, such as elasticity of labor supply and demand for goods, are set to their plausible values[8]. Also, the values in Ballard and Medema(1993)'s research is used for μ and θ, which are the parameters of pollution abatement cost functions that heavily affects producer behavioral change[9].

8) In the central case simulations, uncompensated labor supply elasticity is set to 0.1, while compensated elasticity is applied to 0.2. The price elasticity of taxed goods, -0.7 is set to uncompensated, -0.5 is set to compensated. For the case of non-homothetic utility case, the degree of non-homotheticity could be controlled by the ratio of (D*/D), and it is applied to 30% in central case simulations. More detailed values of key parameters could be found in the appendix.

The impact that the implementation of environmental tax policy has on the efficiency on the tax system is estimated by calculating the marginal excess burden of taxation, in which is used in most relevant researches. It may be calculated through the following equation.

$$\text{Marginal excess burden of taxation} = \frac{\text{Change in consumer's welfare level}(EV_b - EV_r)}{\text{Revenue from labor income tax that changed into environmental tax}} \quad (11)$$

EV_b and EV_r in equation (11) are the equivalent variations for before and after the tax reform[10]. The following table shows the result of the simulation.

Table 1 Simulation results under the assumption of non-homothetic utility function

Scale of Policy Change (represented in percentage points by which labor tax is reduced)	Marginal Excess Tax Burden		
	Output Tax	Emission Tax	Difference in Rate of Change Between Tax Policies
0.01%p.	-2.0973	-2.1085	1.12%
0.02%p.	-2.0815	-2.0928	1.13%
0.03%p.	-2.0675	-2.079	1.15%

Under the assumption of non-homothetic utility function, revenue neutral environmental tax reforms bring gain in tax efficiency. The negative (-) value of marginal excess tax burden indicates enhancement in tax efficiency due to the tax reform, whereas a positive (+) value means a decrease in tax efficiency. In the case of changing pre-existent labor income tax to environmental tax, as shown in the simulation result, revenue neutral environmental tax reforms can improve tax efficiency regardless of the form of environmental tax. Analysis have shown that in both cases in which environmental tax is either levied in the form of consumption tax on the final output or in the form of

9) As in the Ballard and Medema (1993), the key parameter values of the abatement costs function for producer are μ =0.0052, θ =1.25, and the scale of environmental external damage is assumed to 3% of total production.

10) According to the definition of equivalent variation, the changes of consumer's welfare is measured by the difference between level of utility multiplied by ideal price index in bench mark case (Ub*Pb) and level of utility in revised case multiplied by ideal price index of benchmark case (Ur*Pb).

emission tax on pollution itself, the value of marginal excess burden is negative(-), which signifies improvement in tax efficiency[11]. This effect gradually decreases when the scale of policy change increases, showing that it may be dependent on the relative size of the two effects in environmental tax reform, the revenue recycling effect (RE) and tax interaction effect (IE)[12]. Specifically, the revenue recycling effect positively impacting the tax efficiency generates in correlation with the scale of policy change, while the tax interaction effect negatively impacting it exponentially increases according to the policy change. Therefore, upon the point where the scale of policy change increases up to a certain level, the efficiency improvement effect dissolves.

The enhancement effect of the environmental tax efficiency, which is the core of this analysis, differs on the form of taxation. It proves to be relatively more effective in the case where environmental tax is levied as emission tax instead of consumption tax. By comparing the efficiency of the form of tax under the same policy changes, emission tax was shown to be approximately 1.1% higher in terms of improvement of tax efficiency. Thus, the analysis accords with the theory that the closer the tax is to the polluting goods, tax efficiency is enhanced.

This result presents a similar pattern when homotheticity is assumed to the utility function. The simulation results are summarized in the following:

Table 2 Simulation results under the assumption of non-homothetic utility function

Scale of Policy Change (represented in percentage points by which labor tax is reduced)	Marginal Excess Tax Burden		
	Output Tax	Emission Tax	Difference in Rate of Change Between Tax Policies
0.01%p.	0.01382	0.0027	1.11%
0.02%p.	0.03122	0.0200	1.12%
0.03%p.	0.04592	0.0345	1.14%

Contrary to non-homothetic case, when homotheticity is granted in utility function, revenue neutral environmental tax reform could not bring the gain in tax efficiency. The

11) This conflicts with Goulder (1995). Refer to Kim (2000) for detailed discussions.

12) For detailed discussions on the specific types of non-homotheticity of utility function and double dividend hypothesis could be found in Kim(2000, 2002) and Ballard et.al.(2005)

marginal excess burdens incurred by the tax reform were all positive (+), regardless of the form of tax. This seems to be the result of the homothetic assumption of utility function.

An interesting point is that the efficiency difference among the forms of tax are similar, despite that the environmental tax policy has no effect on the tax efficiency. Particularly, environmental tax as emission tax was more effective than consumption tax. According to the simulation results, leaving the scale of policy changes equal, emission tax was shown to be approximately 1.1% higher in terms of efficiency than consumption tax. This can be acknowledged as a similar pattern to assumption of non-homotheticity in the aspect of the direction or scale of the analysis. Hence, regardless of functional form assumption in the utility function, the emission tax was assessed to be more effective.

How can this result be deducted? In order to find the reason, this study compared tax rate of environmental tax that corresponds to equivalent size of policy change. The following shows the required tax rates for output tax and emission tax, to achieve revenue neutrality.

Table 3 Environmental Tax Rates that can achieve revenue neutrality.

Percentage point reduction in Labor tax rate	Non-Homothetic Utility		Homothetic Utility	
	Output Tax	Emission Tax	Output Tax	Emission Tax
0.01%p.	0.0672	0.0654	0.0778	0.0749
0.02%p.	0.1386	0.1308	0.1612	0.1498
0.03%p.	0.2144	0.1963	0.2506	0.2247

As depicted in the table above, emission tax rate was comparatively lower than that of output tax to reach revenue neutrality. Also, the pattern of this result is same for the both types of utility function. That is, revenue neutral environmental tax rate is lower in emission tax replacement case than the case of output tax, whether the utility function is assumed to be homothetic or not. Since the marginal excess burden of tax is sensitive to the tax rate, so it rapidly increases then tax rate is raised. Therefore, in order to have better tax efficiency, the tax authority has to choose the one with lower rate. This implies that when the tax authority considers to introduce environmental tax, the emission tax should be preferred, since adopting the environmental tax in the form of emission tax could bring more effective outcome in the sense of tax efficiency[13].

Ⅳ. Conclusion

The results of this study imply that the enhancement effect on the tax efficiency, which can be caused by tax reform, may vary according to the taxation format of the environmental tax. It also analyzes that the emission tax is more effective than the output tax, in terms of tax efficiency. This result can be interpreted as a supportive claim for previous research implies that tax efficiency is likely to improve when taxes go straight to the pollutant[14]. The emission tax, which is directly imposed on the induced pollution, tends to be taxed more closely than the consumption tax, which is imposed to the consumption of final output or intermediate goods. Therefore, because it is imposed more directly to the taxation article, the emission tax is better in terms of tax efficiency compared to the tax being imposed indirectly on consumption of output. Such arguments are thought to have a thread of connection on the discussion on the efficiency of direct tax and indirect tax.

The conclusion of this study is deemed to contain political implications related to the adoption of environmental tax in Korea. While earlier discussions on environmental tax policy were focused on whether it be introduced and when, but it is more than fact that the discussion on the specific form of taxation was lacked.

In a sense, this is realistic, since most of the current environmental taxes in the world are imposed on the final output or the intermediate good in the form of consumption taxes. In fact, except for a few sporadic occasions, even the earliest adopters of

13) Refer to Kim (2011) for the discussions regarding the effects on the key variables of environmental tax reform.

14) The conclusions are similar to the analysis of Fullerton et. al., as previously examined. It has been noted that the consumer welfare level can be much higher in the case of levying emission tax compared to that of output tax. In this sense, although the focuses are not same, the conclusion of Fullerton et.al. is relevant to this study which theorizes that emission tax is more effective.

environmental tax levy in the form of consumption tax. This results from considering the realistic facts such as the availability of taxation and practical feasibility, rather than the lack of understanding that the proximate taxation of the pollutant is more efficient. When in the first stage of adopting environmental tax, it is seen that consumption taxes on outputs were preferred over emission taxes, since measuring the discharged amount of pollutant or concentration of pollutant was difficult. However, due to the technological progress, it is possible to assume that the government can levy the emission tax, and such changes are to be more simplified as technology develops further. Therefore, it seems necessary to recognize the potential of the emission tax in later discussions on environmental tax policy.

Although this study analyzes the superiority of emission tax in terms of tax efficiency over the standard output tax type one, strict precaution is to be taken to restrict the study results from being over and misinterpreted. The analysis of the study shows quite distinct results, but it is dangerous to conclude that emission taxes are superior in every way, as the result derives from relatively restricted model analysis[15].

As the result of this study suggests, the emission tax is superior in terms of tax efficiency, but the actual taxation should not be evaluated with the sole criterion of efficiency. Realistically, other factors besides efficiency should be considered before introducing a new type of tax imposition that includes environmental tax. Some of these elements consist of the impact that the new tax will have on equity, or the political conflict costs and tax compliance costs among different interest groups. Additionally, the problems of the producer side which may occur during the specific steps of the tax introduction periods, such as the price increase due to tax and the effect it may have on competitiveness on price, and the international competitiveness of domestic products should also be taken into consideration. Moreover, we need to be aware the possibility that big companies may shift tax burdens to small and mid-sized companies in the input process of intermediate goods that may create pollution.

15) As seen in model description chapter, the simulation model is intuitively essential to analyze the mechanism of the tax reform, but rather simple to consider real world economy. For instance, the model employs only labor as an input for production and it does not use real tax data. So the analytic conclusion should be recognized as theoretical result rather than empirical one.

To establish superior environmental tax system, not only the actual taxation availability or technological feasibility, but also the tangible and intangible costs following the taxation should be considered. Taking into account such terms, we cannot conclude that emission tax is completely better compared to output tax. Further discussions on such issues are to be left for future studies.

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Appendix

Derivation of equation (7)

Since the equation (7) stands for the ideal price index for the composite consumption good Q, we need to start with equation (2), the outer nest of utility function.

From the equation (2) and equation (6), we can set up the Lagrangean function as follows:

$$\mathcal{L} = [\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} Q^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} + \lambda(w'T - P_Q Q - w'l - \Gamma) \qquad \text{(A-1)}$$

Solving the equation (A-1) can bring Marshallian demands for the consumer's choice variables, l and Q.

$$l = \frac{\beta I_D}{w'^{\sigma}\Delta} \qquad \text{(A-2)}$$

$$Q = \frac{(1-\beta) I_D}{P_Q^{\sigma}\Delta} \qquad \text{(A-3)}$$

Where I_D is discretionary income, *i.e.*, $I_D = w'T - \Gamma$, $\Delta = \beta w'^{1-\sigma} + (1-\beta)P_Q^{1-\sigma}$

Inserting the demand functions (equation (A-2) and (A-3)) into the utility function (equation (A-1)), can lead us to the indirect utility function V:

$$V = (I_D - \Gamma)\{\alpha P'^{1-\nu}_D + (1-\alpha)P'^{1-\nu}_C\}^{\frac{1}{\nu-1}} \qquad \text{(A-4)}$$

Although the utility function is non-homothetic to the ordinary origin, however the function is still homothetic to the displaced origin. So we have a homothetic relationship between discretionary income and the indirect utility from consumption in excess of the requirements:

$$I_{QD} = I_D - \Gamma \qquad \text{(A-5)}$$

Adopting (A-5) into the indirect utility function(equation (A-4)), and rearranging it with respect to the discretionary income I_{QD}:

$$I_{QD} = V\,\{\alpha P'^{1-\nu}_{D} + (1-\alpha)P'^{1-\nu}_{C}\}^{\frac{1}{1-\nu}} \qquad \text{(A-6)}$$

Thus the ideal price index (P_Q) for the composite good out of discretionary income is:

$$P_Q = \{\alpha P'^{1-\nu}_{D} + (1-\alpha)P'^{1-\nu}_{C}\}^{\frac{1}{1-\nu}} \qquad \text{(A-7)}$$

Derivation of equation (10)

The first order condition of equation (8) with respect to the level of abatement is

$$t_E \mathrm{D} - \frac{\partial \Psi(-\Delta \mathrm{EM}, \mathrm{D})}{\partial \Delta \mathrm{EM}} = 0 \qquad \text{(A-8)}$$

Rewrite equation (A-8) with respect to $t_E \mathrm{D}$, then we could reach to equation (10), which implies that the marginal benefit from abatement is equal to the marginal costs.

Sensitivity Analysis

In this section, the results of sensitivity analysis with respect to the key parameters of simulation model are reported. As briefed in footnote 8, the values of key parameters for central case simulation are summarized in following table.

Table A-1 The values of key parameters for the central case simulations

Parameter	Values	Explanation
η_u	0.1	Labor Supply Elasticity, uncompensated
η_c	0.2	Labor Supply Elasticity, compensated
ε_u	-0.7	Goods Demand Elasticity, uncompensated
ε_c	-0.5	Goods Demand Elasticity, compensated
t_L	40%	Initial Labor Income Tax Rate
θ	1.25	Exponent in Abatement Function
D*/D	30%	Degree of Non-homotheticity

Table A-2 Marginal Excess Burdens Across Different Labor Supply Elasticities (Non-Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	η_u=0.0 η_c=0.1	η_u=0.1 η_c=0.2	η_u=0.1 η_c=0.2	η_u=0.0 η_c=0.1	η_u=0.1 η_c=0.2	η_u=0.1 η_c=0.2
0.01%p.	-1.91826	-2.0973	-2.30679	-1.92812	-2.1085	-2.31934
0.02%p.	-1.90349	-2.0815	-2.28977	-1.91344	-2.0928	-2.30243
0.03%p.	-1.89044	-2.0675	-2.27472	-1.90058	-2.079	-2.2876

Note: η_u stands for uncomepensated labor supply elasticity and η_c stands for compensated elasticity.

Table A-3 Marginal Excess Burdens Across Different Labor Supply Elasticities (Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	η_u=0.0 η_c=0.1	η_u=0.1 η_c=0.2	η_u=0.1 η_c=0.2	η_u=0.0 η_c=0.1	η_u=0.1 η_c=0.2	η_u=0.1 η_c=0.2
0.01%p.	0.01293	0.01382	0.01448	0.00253	0.00270	0.00283
0.02%p.	0.02921	0.03122	0.03271	0.01871	0.02000	0.02095
0.03%p.	0.04294	0.04592	0.04811	0.03226	0.03450	0.03614

Note: η_u stands for uncomepensated labor supply elasticity and η_c stands for compensated elasticity.

Table A-4 Marginal Excess Burdens Across Different Goods-Demand Elasticities (Non-Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	ε_u= -1.0 ε_c= -0.8	ε_u= -0.7 ε_c= -0.5	ε_u= -0.4 ε_c= -0.2	ε_u= -1.0 ε_c= -0.8	ε_u= -0.7 ε_c= -0.5	ε_u= -0.4 ε_c= -0.2
0.01%p.	-1.01583	-2.0973	-2.79382	-1.02136	-2.1085	-2.80958
0.02%p.	-1.00882	-2.0815	-2.77213	-1.0144	-2.0928	-2.78802
0.03%p.	-1.00298	-2.0675	-2.75268	-1.00866	-2.079	-2.76882

Note: ε_u stands for uncomepensated goods demand elasticity and ε_c stands for compensated elasticity.

Table A-5 Marginal Excess Burdens Across Different Goods-Demand Elasticities (Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	ε_u= -1.0 ε_c= -0.8	ε_u= -0.7 ε_c= -0.5	ε_u= -0.4 ε_c= -0.2	ε_u= -1.0 ε_c= -0.8	ε_u= -0.7 ε_c= -0.5	ε_u= -0.4 ε_c= -0.2
0.01%p.	0.00521	0.01382	0.02508	0.00102	0.00270	0.00489
0.02%p.	0.01178	0.03122	0.05667	0.00754	0.02000	0.03625
0.03%p.	0.01735	0.04592	0.08337	0.01303	0.03450	0.06254

Note: ε_u stands for uncomepensated goods demand elasticity and ε_c stands for compensated elasticity.

Table A-6 Marginal Excess Burdens Across Different Initial Tax Rates (Non-Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	t_L=30%	t_L=40%	t_L=50%	t_L=30%	t_L=40%	t_L=50%
0.01%p.	-1.91115	-2.0973	-2.44491	-1.92155	-2.1085	-2.46534
0.02%p.	-1.89698	-2.0815	-2.42652	-1.90747	-2.0928	-2.44702
0.03%p.	-1.88424	-2.0675	-2.41045	-1.89491	-2.079	-2.43113

Table A-7 Marginal Excess Burdens Across Different Initial Tax Rates (Homothetic Case)

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	t_L=30%	t_L=40%	t_L=50%	t_L=30%	t_L=40%	t_L=50%
0.01%p.	0.01340	0.01382	0.01427	0.00262	0.00270	0.00279
0.02%p.	0.03026	0.03122	0.03226	0.01938	0.02000	0.02066
0.03%p.	0.04449	0.04592	0.04746	0.03342	0.03450	0.03566

Table A-8 Marginal Excess Burdens Across Different Abatement Costs (Non-Homothetic Case)

Scale of Policy Change	Emission Tax Replacement				
	θ=1.05	θ =1.15	θ =1.25	θ =1.35	θ =1.45
0.01%p.	-2.10850	-2.10850	-2.10850	-2.10836	-2.10808
0.02%p.	-2.09280	-2.09280	-2.09280	-2.09260	-2.09224
0.03%p.	-2.07914	-2.07908	-2.07900	-2.07875	-2.07828

Note: θ is the exponent in the equation (9), the pollution abatement cost function.

Table A-9 Marginal Excess Burdens Across Different Abatement Costs (Homothetic Case)

Scale of Policy Change	Emission Tax Replacement				
	θ=1.05	θ =1.15	θ =1.25	θ =1.35	θ =1.45
0.01%p.	0.002700	0.002700	0.002700	0.002699	0.002698
0.02%p.	0.020000	0.020000	0.020000	0.019993	0.019981
0.03%p.	0.034501	0.034501	0.034500	0.034484	0.034461

Note: θ is the exponent in the equation (9), the pollution abatement cost function.

Table A-10 Marginal Excess Burdens Across Different Level of Non-Homotheticity

Scale of Policy Change	Output Tax Replacement			Emission Tax Replacement		
	(D*/D)=20%	(D*/D)=30%	(D*/D)=40%	(D*/D)=20%	(D*/D)=30%	(D*/D)=40%
0.01%p.	-1.17479	-2.09730	-3.00952	-1.18102	-2.10850	-3.02559
0.02%p.	-1.16540	-2.08150	-2.98953	-1.17163	-2.09280	-3.00576
0.03%p.	-1.15713	-2.06750	-2.97223	-1.16359	-2.07900	-2.98876

Note: Degree of non-homotheticity is raised as the (D*/D) ratio grows.