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The Effect of Homotheticity on the Double Dividend
and the Optimal Environmental Tax Rate

presented by

Sang-Kyum Kim

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Economics

Charles L Ballard
Major professor

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The Effect of Homotheticity on the Double Dividend and the Optimal Environmental Tax Rate

By

Sang-Kyum Kim

A DISSERTATION

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

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Department of Economics

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ABSTRACT

The Effect of Homotheticity on the Double Dividend and the Optimal Environmental Tax Rate

By

Sang-Kyum Kim

Earlier general-equilibrium studies about the environmental tax reform, represented by Bovenberg and his co-authors, criticized the classical partial equilibrium studies because they neglected the tax-interaction effect, so that they were overly optimistic about the prospects of the environmental tax reform. They also indicate that environmental tax reforms typically exacerbate pre-existing tax distortions, even with full revenue-recycling, so the double-dividend hypothesis will not be materialized.

However, all of the analytical and numerical results of the general-equilibrium studies are based on a very special form of the utility function, so their conclusion is derived by rather predetermined assumptions. To verify this idea, we perform simple static general-equilibrium simulations, with and without the assumption of homotheticity. According to these simulations, we conclude that the result of environmental tax reform is sensitive to the functional assumption, so there should be no presumption on the double-dividend hypothesis. Also, we find that a direct emission tax replacement yields a double dividend, when the non-homotheticity is assumed. In addition, we find that the optimal environmental tax rate of the second-best world could lie below or above the Pigouvian tax rate, depending on the functional assumption.

To my Parents,
To my Wife, my Daughters,
and
To my Mother for her endless love and dedication

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Acknowledgment

I wish to thank the important individuals who made the completion of this dissertation possible. My deep thanks and appreciation go to Dr. Charles L. Ballard who has been my committee chairperson. Without his constant encouragement and insightful comments, this dissertation could never been completed. Truly, he is a great mentor as well as a respectable scholar. I really appreciate his sincere dedications and inspirations.

I gratefully acknowledge Dr. John H. Goddeeris and Dr. Lawrence W. Martin, my other committee members, for their help and valuable comments. My fellow graduate students deserve my thanks for having read and commented on many parts of this dissertation. Especially, I would like to thank Tae Joong Kim, Young Wook Han, Ki Won Kang, Chi Rok Han, and Doug Harris. Also, I want to thank to all Korean economics-graduate students, and members of Korean Buddhist students organization whom I have met here. They have played a major role in developing me as an economist during the days at Michigan State University.

I reserve my very special thanks for my family. My father and mother always supported me and encouraged me to do my best. Indeed, for everything I have got today, I am deeply indebted to them. I would be remiss if I did not thank my brothers and sisters for their love for the years. I would also like to thank my mother-in law and brothers-in law for their support.

However, my greatest debt is to my wife, Sung Hye, for her love, support, and endless sacrifices throughout the process of my graduate studies. Without her patience and support, this dissertation would never have been completed. Finally, I would like to thank to my daughters, Eunice and Lindsey for the full of joy they brought me.

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Chapter I

Introduction

It is widely accepted that environmental taxation is a powerful tool to correct the misallocation of environmental resources. According to the classical theory of externality control, a regulatory agency can place a charge, in the form of unit tax, on the offending activity that is equal to the marginal social damage. Such a Pigouvian tax serves to internalize the social cost associated with an environmental externality, so it can support an economically efficient level of environmental quality. If the environmental tax were the only distortion in the economy, then the externality-correcting tax could be analyzed in isolation. However, real-world economies contain a wide variety of other distortionary taxes. For that reason, it is necessary to consider the interactions among all of the taxes in the economy. In recent years, economists have devoted considerable attention to these second-best issues about the environmental taxation.

An environmental tax can generate tax revenues, as well as correcting the environmental externalities. The tax revenue from the environmental tax can be used in a number of ways, one of which is to reduce the reliance on other distortionary taxes. The term 'double dividend' refers to the fact that an environmental tax can be used not only to improve the environmental quality, but also to reduce the distortionary costs of the tax system.

The central idea of this paper is that (a) the results of the double dividend hypothesis and (b) the optimal level of the environmental tax rate in a second-best world are sensitive to the form of the utility function. A double dividend will usually not be possible if the utility function is homothetic, but double dividends are entirely possible if certain kin

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certain kinds of non-homotheticity are assumed. These results cast doubt on earlier theoretical results, which seemed to suggest that double dividends would be very unusual. Instead, I find that there is no general theoretical presumption against a double dividend. In addition, I find that if we consider the first dividend as well as the second dividend of the environmental tax reform, the effect of the tax reform on the welfare level and overall tax efficiency is substantial, because of the sizable first dividend.

For the optimal level of the environmental tax rate under the second-best situation, by relaxing the assumption of homotheticity, I get different results from the previous theoretical and numerical studies. In the next couple of sections of this introductory chapter, I will briefly review the controversy regarding the double-dividend hypothesis and the optimal environmental tax rate.

I-1. The Double-Dividend Hypothesis

As mentioned earlier, there is reasonable consensus as to the ability of environmental taxes to confer the first dividend (environmental quality improvement), although the precise magnitude of the dividend is generally unknown. This uncertainty regarding the magnitude of the first dividend has served to focus increased attention on the second dividend. This is because, if there is a second dividend from changing the configuration of taxes, then the new environmental policy would have to improve social welfare, regardless of the size of the first dividend. This point is quite important, especially for policy makers. If the policy maker knows that a new environmental policy has tax-related costs that are zero or negative, then he or she may have much less burden in proving

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in proving the efficiency of the new policy, even though the policy maker has incomplete information about the size of the environmental-quality improvement.

According to Goulder (1995), there are three forms of the double-dividend proposition. These are:

- Weak form: By using revenues from the environmental tax to finance reductions in marginal rates of an existing distortionary tax, one achieves cost savings relative to the case in which the tax revenues are returned to tax payers in lump-sum fashion.
- Intermediate form: It is possible to find a distortionary tax such that the revenue-neutral substitution of the environmental tax for this tax involves a zero or negative gross cost[1].
- Strong form: The revenue-neutral substitution of the environmental tax for a *typical* or *representative* distortionary taxes involves a zero or negative gross cost.

Economists generally agree that the weak form of the double-dividend hypothesis holds: A reduction in a distortionary tax is better than a lump-sum rebate of equal size. However, there is much less consensus about the other forms of the double-dividend hypothesis. The main idea of the stronger forms (both intermediate and strong forms) is that the tax reform (introducing a new environmental tax while reducing a preexisting distortionary tax) can have costs that are zero or even negative, where the "costs" of the reform are a measure of the policy-induced changes in individual welfare, abstracting from the effects of the quality improvement. So the stronger forms imply that the tax

[1] According to Goulder, the definition of gross cost is "policy-induced changes in individual welfare (abstracting from welfare effects associated with policy-related changes in environmental quality)". For more detail, please refer to Goulder (1995).

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reform actually improves the welfare of the economy, regardless of whether there is any environmental quality improvement.

Some of the early studies of revenue recycling, such as Terkla (1984), Pearce (1991), and Oates (1993), only consider the problem in a partial-equilibrium framework.[2] Since these partial-equilibrium studies ignore the adverse effect from the possible tax interactions in the general-equilibrium situation, they easily reach a conclusion that environmental taxes would still be worthwhile, even if the environmental benefits were very small. For this reason, the general-equilibrium studies of the double-dividend hypothesis by Bovenberg and his co-authors have attracted considerable attention, because they can catch the adverse effect of the environmental tax reform.

Perhaps the best-known of these papers is the one by Bovenberg and de Mooij (1994). They argue that replacement of a pre-existing tax by an environmental tax of equal revenue will typically reduce welfare (abstracting from the improvement to the environment). The intuition of Bovenberg and de Mooij is that replacing a labor tax with an environmental tax on dirty goods (polluting goods) will upset not only the consumer's choice between leisure and consumption goods, but also the choice between clean and dirty goods. Since the environmental tax has a narrow tax base while the labor tax has a broad one, the environmental tax must be imposed at a rate that is much higher than the reduction of labor tax, to achieve revenue neutrality. As the gross price of the dirty good is increased (due to the high tax on the dirty good), the consumer's demand for the dirty good is decreased, which implies a loss of some of the tax base in environmental taxation. Moreover, the labor supply is decreased by the tax reform, since the tax

[2] Ballard and Medema (1993) employ a general-equilibrium model of taxation with an explicit treatment of environmental pollution. However, they did not focus on the double-dividend issue.

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switching reduces the real wage rate[3]. Thus, the tax bases (of both the environmental tax and the labor tax) are eroded by the environmental tax reform. In turn, the consumer's advantage from the labor tax reduction is shrunk. This is the tax-interaction effect[4]. So the consumer's benefit from the labor-tax reduction is offset completely by the disadvantage from the high environmental tax. In other words, the arguments of Bovenberg and de Mooij imply that the intermediate and strong forms of the double-dividend hypothesis are generally not correct. The main contribution of Bovenberg and de Mooij (1994) is probably that they analyze the double-dividend hypothesis in a general-equilibrium framework, and find the tax-interaction effect.

Parry (1995) reaches similar conclusions about the double dividend of environmental taxation, using a somewhat different approach. He subdivides the total effect from an environmental tax into a 'revenue effect' (RE) and an 'interdependency effect' (IE). The RE refers to the welfare gain from the reduction of pre-existing distortionary tax with environmental tax revenue, and the IE refers to the exacerbation of pre-existing tax distortions due to the environmental tax reform. He points out that the previous partial equilibrium analyses fail to recognize the IE, so these studies have been overly optimistic about the double dividend of an environmental tax. According to Parry, the double-dividend hypothesis could only be correct when the RE outweighs the IE, and this is possible only when the dirty good is a sufficiently weaker-than-average substitute for leisure.

Bovenberg and Goulder (1997) employ both analytical methods and numerical simulations to show that the revenue-neutral environmental tax reform typically generates

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[3] Note that this assumes a positive labor-supply elasticity.

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a gross cost, so the double dividend does not materialize. According to them, environmental taxes can be viewed as *implicit* taxes on labor and, as a result, the revenue-neutral substitution of an environmental tax for a tax on labor usually does not reduce labor's true overall tax burden. The logic behind their argument is such a tax swap usually increases labor's tax burden, because an implicit labor tax in the form of an environmental tax is less efficient in terms of raising revenue than an explicit labor tax. They also argue that under the desirable range of key parameters, double-dividend results are not yielded in the numerical simulations.

Böhringer, Pahlke, and Rutherford (1997) conclude that environmental tax reforms have to be justified on the basis of environmental benefits and cannot be considered a "no-regret" strategy, since their numerical simulations show that the double-dividend hypothesis fails under a range of plausible specifications of revenue replacement methods, and parameter values. However, they add that the prospect of a double dividend may significantly increase in a third-best setting, where initial taxation is inefficient and additional market distortions (e.g., wage rigidities) exist.

Goulder, Parry, Williams III and Burtraw (1998) also reach similar conclusions to those of Bovenberg and de Mooij (1994) about the double dividend of environmental tax reform. Using numerical simulation, they find that pre-existing taxes significantly raise the cost of all environmental policies (such as emission taxes, emission quotas, fuel taxes, and mandatory technologies) relative to their costs in a first-best world. The implication of their conclusion is that the double-dividend hypothesis of environmental taxation is not correct, due to the tax-interaction effect.

[4] Bovenberg and de Mooij (1994) named it the "Tax-base-erosion effect". In Goulder (1995), it is called the "Tax-interaction effect" as a general term.

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Most of the general-equilibrium studies are pessimistic about the double dividend of environmental taxation. With both analytical and numerical methods, they found that the disadvantage of the environmental tax reform (e.g., the tax interaction effect) is greater than the benefit of it (e.g., the revenue-recycling effect).

The interesting fact of these studies is that all of the general-equilibrium results are based on similar functional-form assumptions. Especially, most of the analytical and numerical models use (nested) constant elasticity of substitution (CES) or Allen elasticity of substitution (AES) utility functions for the consumer's preferences[5]. These functional forms are homothetic in character. This fact is quite important, because we may reach entirely different results by relaxing the homotheticity assumption.

As I mentioned earlier in this chapter, the purpose of this dissertation is to demonstrate that the conclusions of the earlier general-equilibrium studies that tend to reject double-dividend hypothesis depend seriously on functional assumptions, so that their results lack generality. I will show that their results come from a very restrictive set of assumptions regarding the form of utility function. So in this study, I will use the model of Bovenberg and de Mooij (1994) as a representative model in proving my idea.

I-2. The Optimal Level of Environmental Tax Rate

It is well known that in the absence of any other distortions or market imperfections, the optimal level of the environmental tax rate is equal to the marginal external damage. However, recent studies have suggested that the optimal level of environmental tax rate in a second-best situation is less than that of the first-best world, due to the

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due to the tax interaction-effect. Several studies employed either analytical or numerical methods (or both) to prove this idea. I will briefly review the arguments of those studies in this subsection.

Bovenberg and de Mooij (1994) use analytical methods to show that the optimal pollution tax typically lies below the Pigouvian tax, due to the tax-interaction effect between the pre-existing distortionary tax and the newly introduced environmental tax. According to them, since the negative effect of the environmental tax on labor supply is larger than the positive effect of the labor-tax reduction on labor supply, the optimal environmental tax rate is smaller than the Pigouvian tax rate.

In response to this argument of Bovenberg and de Mooij, Fullerton (1997) points out that there exist some possibilities under which the optimal environmental tax rate could be higher than the Pigouvian tax rate. By using a similar analytical model to the one that Bovenberg and de Mooij used, Fullerton shows that when the only initial distortionary tax is imposed on clean good consumption rather than labor income, the optimal environmental tax rate could be higher than Pigouvian tax rate. However, if the only initial distortionary tax is imposed on labor income (the case of Bovenberg and de Mooij), then the optimal environmental tax rate must lie below the Pigouvian tax rate. So, in this sense, even though Fullerton points out the possibility that the optimal environmental tax rate could be higher than Pigouvian tax rate, basically his paper confirms the argument of Bovenberg and de Mooij.

Meanwhile, Parry (1995) calculates the optimal environmental tax rate under the second-best world, using numerical simulations. He suggests that under the plausible combination of parameters, the optimal environmental tax rate is about 63 percent to 78

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[5] Parry (1995) uses AES utility function, and the AES utility function is also homothetic in character.

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percent of the marginal external damage (*i.e.*, 63% ~ 78% of the Pigouvian tax). So his result also supports the claim of the Bovenberg and de Mooij numerically.

Using a computational general-equilibrium (CGE) model, Bovenberg and Goulder (1996) also calculate the optimal level of environmental tax in the second-best world. They employ a detailed numerical model for the simulation, which has intertempotral preferences for the consumer and disaggregates the production side of the model into 13 sectors. They conclude that, due to the tax-interaction effect, the optimal level of the environmental tax rate is 6 to12 percent less than the marginal externality (so, 88 to 94 percent of the Pigouvian tax) in the second-best situation.

Unlike previous studies, Cremer, Gahvari, and Ladoux (2000) advocate that the argument of Bovenberg and de Mooij is correct only when some special conditions are assumed, and one cannot draw general results regarding the relative size of environmental levies and Pigouvian taxes. They focus on the relationship between environmental quality and labor supply to investigate the relative size of the environmental tax and the Pigouvian tax. However, since their model is a purely analytical one, they do not suggest the magnitude of optimal environmental tax rate.

As we reviewed, most of the numerical studies reach the conclusion that in the second-best world, the optimal level of environmental tax rate lies below the Pigouvian tax rate. However, one common fact of those studies is that they are based on the same functional-form assumption of the utility function. As in the case of the double-dividend hypothesis, it is possible that we may reach different results about the optimal environmental tax rate if we employ a different functional-form assumption. By relaxing the assump

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In addition, I will investigate the effect of producer side abatement, by employing direct taxation on the pollution, instead of using a proxy tax on the consumption goods, in Chapter IV. About this issue, Goulder (1995) indicates that a double dividend is impossible, since a producer side tax on the pollution also causes the tax-interaction effect. In order to check the generality of Goulder's idea, I perform a set of simulations, with and without the homotheticity assumption. The general results of the simulations are that the previous theoretical conclusion is only correct under the specific functional-form assumption (homothetic utility function), and a double dividend is possible if we relax the key assumption.

I-3. Central Idea of This Research

In this dissertation, I will show how the functional assumption affects the conclusions regarding (a) the double-dividend hypothesis, and (b) the optimal environmental tax rate. As I mentioned earlier, most of the numerical results about (a) and (b) come from models that employ the homotheticity assumption in the utility function. My hypothesis is that the results of Bovenberg and his co-authors are driven by the rather artificial assumption of homotheticity. To show whether my hypothesis is correct, I will use a computational general-equilibrium (CGE) approach. For the analytical and numerical model, I will use the model of Bovenberg and de Mooij (1994), as a representative one.

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Chapter V.

In Chapters II and III, I will perform some simple static simulations to show how the different functional-form assumptions affect the results regarding the double dividend of environmental taxation. In addition, I will present the optimal level of environmental tax rates across the different functional assumptions. In Chapter IV, I will employ a different policy change, *i.e.*, a pollution tax on the producer side, and see how the different functional-form assumption affects the simulation results. I will discuss several key findings and simulation conclusions derived from different models in the conclusion Chapter V.

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Chapter II

Simulations with Homothetic Utility

In this chapter, I will perform simple general-equilibrium simulations to verify whether the double-dividend of the environmental tax reform is possible under the assumption of homothetic utility. In order to reach a clear conclusion, I will use the same assumptions that Bovenberg and de Mooij (1994) used, such as a homothetic and separable utility function, linear production technology, and revenue-neutral tax policy. While we hold the key assumptions that Bovenberg and de Mooij made, we will perform two different simulations. One considers only the second dividend, and the other considers both the first and second dividends at the same time. In section II-1, we will use a utility function that does not contain the first dividend factor, *i.e.*, a utility function that does not include environmental damage. In section II-2, we will use a utility function that contains the environmental damage. So the simulation results from section II-1 will clearly show us the pure effect of the second dividend on the consumer's welfare change and the tax efficiency, abstracting from the first dividend. Similarly, the simulation results of section II-2, along with the simulation results from section II-1, will enable us to figure out the effect of the first dividend easily, so that we could measure and compare the effects of the first and second dividends.

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II-1. Homothetic Utility Function without Environmental Externality Factor

Since the main controversy of the current double dividend debate is the existence of the positive second dividend, the utility function of this section will not include the environmental externality, so that we may focus exclusively on the second dividend.

Here, I will build a model following the assumptions that Bovenberg and de Mooij (1994) made. The key assumptions are:

- Homothetic and separable utility function
- Linear production technology with labor input only
- Revenue-neutral replacement of labor income tax with environmental tax (tax on consumption of the dirty good)

A. Model

Bovenberg and de Mooij (1994) assume that the consumer's utility function is homothetic and separable. These characteristics are shared by a constant elasticity of substitution (CES) utility function. Consequently, we will use a nested CES utility function, which is also used in many other studies.

The leisure/labor choice is characterized by the outer nest of the utility function, which is defined over leisure, l, and consumption of a composite good, X:

$$(II-1) \qquad U = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

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where σ is the elasticity of substitution between leisure (l) and the composite good X, and β is a weighting parameter.

The consumer's problem is to maximize (II-1), subject to the budget constraint:

$$(II-2) \qquad w'T = P_X X + w'l$$

where l is leisure,

X is consumption of the composite good,

T is the time endowment for labor(L)/leisure(l), so T=L+l,

w' is the net-of-tax price of leisure/labor, so ($w' = w(1 - t_L)$), where w is the gross wage rate and t_L is the labor tax rate, and

P_X is the price of consumption goods, including any taxes.

The budget constraint indicates that the consumer's full income can be allocated to consumption of leisure or to consumption of goods.

Equations (II-1) and (II-2) are used to set up the Lagrangean function:

$$(II-3) \qquad £ = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} + \lambda(w'T - P_X X - w'l)$$

The first-order conditions of the choice variables (l,X) are,

$$(II-4) \qquad \frac{\partial £}{\partial l} = \beta^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} l^{\frac{-1}{\sigma}} - \lambda w' = 0$$

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$$(II-5) \qquad \frac{\partial \pounds}{\partial X} = (1-\beta)^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} X^{\frac{-1}{\sigma}} - \lambda P_X = 0$$

After some algebra, we get the Marshallian demand functions for l and X:

$$(II-6) \qquad X = \frac{(1-\beta) \cdot I}{P_X{}^{\sigma} \Delta}$$

and

$$(II-7) \qquad l = \frac{\beta \cdot I}{w'^{\sigma} \Delta} \ ,$$

where $I = w'T$ (*i.e.*, I is the consumer's "full income"), and

$$\Delta = \beta w'^{1-\sigma} + (1-\beta) P_X{}^{1-\sigma} .$$

The inner nest of the consumer's utility function determines the allocation of the composite consumption good, X, between "clean goods"(C) and "dirty goods" (D). Good C is assumed not to generate an environmental externality, while good D does have a pollution externality. The inner nest of the utility function for goods consumption is:

$$(II\text{-}8) \qquad X = \left[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}$$

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where ν is the elasticity of substitution between the dirty good and the clean good, and α is a weighting parameter.

The budget constraint for the inner nest states that the consumer's net money income should be equal to the gross expenditure on the two goods:

$$(II\text{-}9) \qquad w'L = P_D'\,D + P_C'\,C$$

where $P_D' = P_D(1+t_D)$, $P_C' = P_C(1+t_C)$.

We construct a Lagrangean function on the basis of equations (II-8) and (II-9).

$$(II\text{-}10) \qquad \pounds = \left[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} + \lambda\,[w'L - P_D'\,D - P_C'\,C]$$

The first-order conditions of the choice variables are

$$(II-11) \qquad \frac{\partial \pounds}{\partial D} = \alpha^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} D^{\frac{-1}{\nu}} - \lambda P'_D = 0$$

and

$$(II-12) \qquad \frac{\partial \pounds}{\partial C} = (1-\alpha)^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} C^{\frac{-1}{\nu}} - \lambda P'_C = 0$$

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After some algebra, we get the demand function for dirty goods and clean goods:

$$(II-13) \qquad D = \frac{\alpha \cdot I_X}{P'^{v}_{D}\,\Omega}$$

and

$$(II-14) \qquad C = \frac{(1-\alpha) \cdot I_X}{P'^{v}_{C}\,\Omega} \quad ,$$

where $I_X = w'L$ is net money income that is available to be spent on consumption goods, and $\Omega = \{\alpha P'^{1-v}_{D} + (1-\alpha) P'^{1-v}_{C}\}$.

Now, let's consider the production side of this model. We follow Bovenberg and de Mooij by assuming linear production technology in each of the two sectors, which use labor input only:

$(II\text{-}15) \qquad D = A_D\, L$

$(II\text{-}16) \qquad C = A_C\, L,$

where A_D and A_C are scale parameters.

By the given information, the producer's profit function can be rewritten as

$(II\text{-}17) \qquad Profit_i = (P_i\, A_i - w)\, L_i \qquad \text{for } i = C,D$

where i indexes each industry.

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appendix.

The producer's supply decision depends on the sign of the first term of the right–hand side of equation (*II*-17). Intuitively, there are three possible scenarios for the producer, but we use the standard zero-profit assumption, which implies that $P_i A_i = w$.

In this simple model, the government may levy taxes on labor, and on purchases of good D, and all of the government's tax revenues are devoted to exhaustive expenditures on the two goods. In other words, we abstract from transfer payments.

The government budget constraint is

(*II*-18) $$w\, t_L L = P_C C_{Gov} + P_D D_{Gov}.$$

where C_{Gov} is government demand for the clean good, and D_{Gov} is government demand for the dirty good.

The government allocates its expenditures to good C and good D on the basis of a utility function. In order to abstract from uses-side effects in our simulations, we assume that the government's utility function has the same parameters as those in the inner nest of the consumer's utility function. Note that it is assumed that the government does not pay tax on its purchases.

Using standard techniques, we calibrate the parameters of the production and utility functions. A detailed description of the calibration procedure is found in an appendix.

B. Simulation

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B. Simulation Methods

After the calibration procedures have been performed, the model is ready to perform simulations. In the base case, the labor tax is the only tax to be collected by the government in the economy. In the revised case, a portion of the labor tax is replaced by an environmental tax (a commodity tax on the dirty good D) in a revenue-neutral manner.

We will investigate the results of the new policy on consumer's welfare by calculating the equivalent variation (E.V.), along with the marginal excess burden of new tax system (M.E.B.)

From the consumer's demand functions, we derive the indirect utility function (V), expenditure function (E) and price index (P*).

$$(II-19) \qquad V = I \cdot \{\beta w'^{1-\sigma} + (1-\beta)P^{1-\sigma}\}^{\frac{1}{\sigma-1}}$$

The indirect utility function, V, is the direct utility function, U, with demand functions substituted in.

$$(II-20) \qquad E = V \cdot \{\beta w'^{1-\sigma} + (1-\beta)P^{1-\sigma}\}^{\frac{1}{1-\sigma}}$$

The expenditure function, E, is income solution of indirect utility function.

We can use a nice property of homothetic and separable utility functions in getting the ideal price index P*.

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$$(II-21) \qquad P^* = \{\beta w'^{1-\sigma} + (1-\beta)P^{1-\sigma}\}^{\frac{1}{1-\sigma}}$$

With the indirect utility function and the price index, we can evaluate the welfare change from the new policy.

The equivalent variation is

(*II*-22) $\quad EV = (V_b - V_r)\, P_b^*,$

where the subscript 'b' stands for base case, and the 'r' stands for revised case.

The marginal excess burden stands for the differential welfare cost per dollar of revenue, given by

(II-23) MEB

$$= \left[\frac{-\,Change\ \ in\ \ Consumer\ \ Welfare}{Amount\ \ of\ \ Distortionary\ \ Tax\ \ revenue\ \ replaced\ \ by\ \ Environmental\ \ Tax}\right]$$

C. Simulation Results

Our simulation results confirm the idea of Bovenberg and de Mooij (1994) that rejects the double-dividend hypothesis of environmental tax reform. The simulation results show that the new tax policy (introducing the environmental tax) generates an efficiency loss. In the sensitivity tests, under a variety of reasonable values of the labor-supply elasticities and goods-demand elasticities, the double-dividend hypothesis is also rejected. Thus, if we use the assumptions of Bovenberg and de Mooij, we get simulation results that are consistent with their theoretical results.

In the central case of the simulations, I set the 4 elasticities to the most desirable values that are recommended by related econometrics literatures. Since the consumer in this simulation model is allowed to choose its labor supply and leisure demand based on the time endowment and the change of wage rate, the simulation results largely depend on the parameters of the labor supply. Thus, finding the most suitable labor supply parameters is very important in this simulation. It is widely accepted by the most economists that the labor supply curves of males are rather inelastic, or slightly backward-bending. Thus, many labor economic[6] studies suggest that the reasonable range of the uncompensated labor-supply elasticity is between –0.1 and 0.1 for men, since those numbers reflect this fact well. However, unfortunately, there is some controversy about the labor-supply elasticity for women[7]. Earlier labor economists[8] estimate that women's labor-supply elasticity is quite large, substantially larger than men's one. They used simple econometric techniques on cross-section data, so they generally did not consider some problems in estimating labor supply, such as the sample selection problems, non-linear budget constraint, etc. The labor-supply elasticity of females estimated by these studies is about one-half, with wide variations. Later studies[9] employ other econometric techniques to handle the problems of the previous ones, but their estimation of the labor-supply elasticity of females is substantially higher than previous one. However, more

[6] See Killingworth (1983), pp. 119-125. Also see Hansson and Stuart (1985).
[7] An excellent review is presented in Ballard (1987).
[8] The first-generation studies of labor supply estimation, represented by Cain and Watts (1973).
[9] The second-generation studies, represented by Heckman (1976), Hausman (1981), and Cogan (1980)

recent studies[10] point out that the earlier studies made critical assumptions in estimating the women's labor-supply elasticity, which tend to enlarge the estimating values. They argue that under more realistic assumptions, the labor-supply elasticity of women is much smaller than the one estimated by earlier studies.

Since the simulation model in this research uses a labor supply elasticity that is a weighted average of male and female responses, I will use 0.1 for the uncompensated labor-supply elasticity (η_u) and 0.2 for the compensated labor-supply elasticity (η_c) for the central-case simulations.

Like the parameters of the labor behavior, the parameters in goods demand also play important role in this simulation. In this research, I will assume that the dirty good (good D in this model) is an energy-related polluting good. Thus, I set the value of the dirty-good-demand elasticities based on suggested values from the related studies. Most of the studies[11] about energy goods suggest that the own price elasticities of the polluting goods are quite small, especially in the short run. So in the central-case simulations, I will use –0.7 for the uncompensated good demand elasticity (ε_u), and –0.5 for the compensated elasticity (ε_c) as the average of the short run and the long run.

In most of the simulations in this chapter, the proportion of expenditure on dirty good consumption (good D) is set to about 22 percent of consumer's net income (after tax labor income), while the proportion of expenditure on the clean good (good C) is set to about 78 percent of consumer's net income. In terms of the GDP, the dirty good accounts for about 13 percent of GDP in the base case. Note that these numbers do not

[10] See Thomas A. Mroz (1987).
[11] Well organized results are provided in Nordhaus (1997). See Nordhaus (1997), pp. 24 – 32.

exactly reflect the expenditure share suggested by related-econometric studies[12], but the values employed in this simulation are actually located in the reasonable range of the suggested values. Throughout the simulation, labor's share of national income (GDP) is 100 percent. In most of the simulations, the only tax is a 40-percent tax on labor income in the base case, except for the sensitivity analysis with respect to the initial labor-tax rate. In the revised-case simulations, labor taxes are reduced by integer-multiples of one percentage point, and are replaced by environmental taxes. The central case simulation results are briefly reported in Table II-1 below.

Table II-1. Simulation Results of the Central Case

Labor Tax Rate in the Revised Case	Environmental Tax rate	Marginal Excess Burden
0.39	0.0778	1.0739%
0.38	0.1612	2.1018%
0.37	0.2506	3.0803%

When we reduce the labor tax from 40 percent to 39 percent, the lost tax revenue is made up through a tax on the dirty good, and the increase in the commodity tax on the dirty good must be greater than one percentage point. This is because the tax base for the dirty good is much narrower than the tax base for the labor tax: In many of the simulations reported in this chapter, we assume that the dirty good accounts for about 13 percent of GDP in the base case. On the other hand, labor accounts for 100 percent of

[12] See Blundell (1988)

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GDP in this simple one-factor model. For our central-case parameters, the tax rate on the dirty good that is necessary to recover the lost revenue is 7.78 percent, when the labor tax rate is reduced from 40 percent to 39 percent. From Table II-1, we find more information about the environmental tax rate that is necessary to recover the revenue lost from the labor tax reduction. As we reduce the labor tax rate more, the environmental tax rate that is necessary to preserve revenue neutrality becomes larger rapidly. When the labor tax reduction is 2 percentage points, the necessary environmental tax rate is 16.12 percent, and if the labor tax reduction is 3 percentage point, the environmental tax rate is 25.06 percent. So the environmental tax rates that are necessary to maintain the revenue neutrality are non-linearly increased as the labor tax reduction is increased. This pattern is quite consistent for larger tax policies.

The key idea that constitutes the conclusion of Bovenberg and de Mooij is the tax-base erosion effect. According to Bovenberg and de Mooij, the environmental tax reform will reduce the tax base of the environmental tax as well as the tax base of the labor tax. Because of the higher tax rate on the dirty good, the demand for the dirty good will be decreased, so that the tax base of the environmental tax is decreased. At the same time, the tax base of the labor tax is decreased, because the real wage rate is decreased due to the higher tax on the dirty good[13]. These simulation results confirm the idea of Bovenberg and de Mooij, since, as they expected, both of the tax bases (environmental tax and labor tax) are decreased by the new tax policy.

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[13] Due to the size difference in the tax bases, it is true that the change in environmental tax rate is larger than the change of labor tax rate reduction (*i.e.*, $|\Delta t_D| > |\Delta t_L|$). So the force to increase the price by a higher environmental tax rate (t_D) outweighs the force to decrease the price by a labor tax reduction (t_L). Thus the price (index) is increased. Also the real wage (w/p) is decreased. Since the labor supply depends solely on the real wage (due to the separability assumption), the labor supply will fall, as long as labor-supply elasticity is positive.

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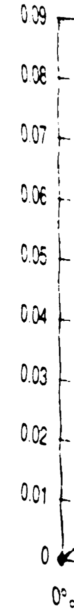
The last column of Table II-1 presents the marginal excess burden of the environmental tax reform. The marginal excess burden stands for the differential welfare cost per dollar of revenue (refer to equation (II-23) for definition of MEB). The marginal excess burdens are all positive, when the environmental tax reform takes place, which means the tax reform generates gross efficiency cost.

According to the central-case simulation results, a larger tax reforms yields larger efficiency costs. However, one interesting fact about the marginal excess burden is that, although we get positive efficiency costs, the magnitudes of the marginal excess burden are still relatively small even in the case of a relatively large tax reform. This fact may serve to highlight an important issue about environmental policy. Although the environmental policy simulated here is not a 'no-regret' strategy[14], the potential for the environmental tax reform is still alive, because the efficiency cost of the environmental tax reform is relatively small. In other words, even if the double-dividend hypothesis is not correct due to the negative second dividend, the core idea of the pollution-control theory is still in effective, because even a small first dividend would be sufficient to generate a net gain for society.



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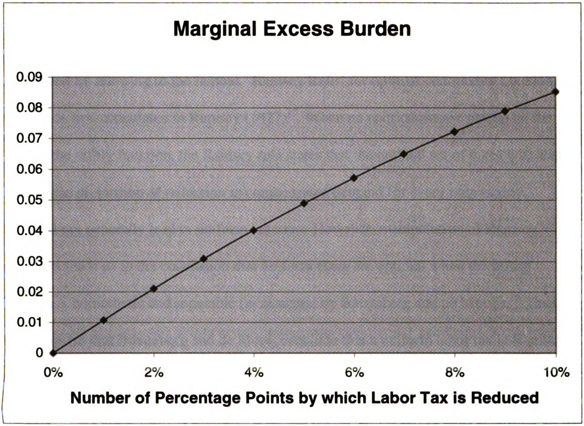

Figure II-1. Marginal Excess Burden by the Environmental Tax Reform

[14] See Böhringer, Pahlke and Rutherford (1997).

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So far, we have found simulation results that are consistent with the theoretical results of Bovenberg and de Mooij (1994). However, we need to focus on the fact that those simulation results are made within the assumptions that Bovenberg and de Mooij made. In fact, it is not at all surprising that we should be able to confirm the ideas of Bovenberg and de Mooij (1994) under their very strong assumptions. This can be understood by referring to the famous "Ramsey Rule" for optimal commodity taxation, which was first articulated in Ramsey (1927)[15]. When no restrictions are placed on the form of the utility function, the Ramsey rule states that the optimal set of taxes will lead to the same proportion of reduction in compensated demand for every commodity. This will not generally lead to uniform tax rates. However, manipulation of Ramsey's equations leads us to the conclusion that uniform taxes are optimal when the utility function is homothetic and separable (as assumed by Bovenberg and de Mooij).[16] Thus, it is no surprise that Bovenberg and de Mooij conclude that a uniform labor tax is Ramsey optimal. They employ the assumptions that are necessary, within a Ramsey framework, for uniform taxation, and they conclude that uniform taxes are optimal.

Since Bovenberg and de Mooij assume a tax system that is Ramsey optimal, any tax reform that deviates the economy from the initial situation (which is optimal) obviously leads the economy to an inefficient situation. This is the reason that Bovenberg and de Mooij reject the double-dividend hypothesis, even though they do not emphasize this point. In this sense, I do not claim that Bovenberg and de Mooij are incorrect, given their assumptions. Rather, my emphasis will be on showing that the results are critically

15 An excellent exposition of the Ramsey literature can be found in Sandmo (1976).

16 In the context of static models, such as those used by Ramsey and by Bovenberg and de Mooij, uniformity can be achieved either by taxing all commodities at the same rate, or by having a tax on labor only.

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sensitive with respect to some of the underlying assumptions. If the assumption of homotheticity is relaxed, the conclusions of Bovenberg and de Mooij are contradicted, as we will see in the next section.

D. Sensitivity Analysis

In this section, I will report the results of sensitivity analyses with respect to two important elasticities of the model – the labor-supply elasticity (η) and the demand elasticity for the dirty good (ε), and the level of initial tax rates on the labor income. During the sensitivity tests for the each elasticity, in order to provide a clear analysis, I will fix one elasticity while changing the other one.

D-(1). Sensitivity Analysis with respect to the Labor-Supply Elasticity (η)

In this analysis, I will test values ranging from -0.1 to 0.3 for the uncompensated labor supply elasticity (η_u), and from 0.0 to 0.5 for the compensated labor supply elasticity (η_c). The demand elasticities for the dirty good are fixed at –0.7 for the uncompensated elasticity (ε_u), and -0.5 for the compensated elasticity (ε_c). Also, the labor tax rate in the base case is set to 40 percent. A brief summary of the sensitivity test result is presented in the following table.

Table II-2. Marginal Excess Burden, across different Labor Supply Elasticities (η)

Percentage-Point-Reduction in the Labor Tax Rate	$\eta_u = -0.1$, $\eta_c = 0.0$	$\eta_u = 0.0$, $\eta_c = 0.1$	$\eta_u = 0.1$, $\eta_c = 0.2$	$\eta_u = 0.2$, $\eta_c = 0.3$	$\eta_u = 0.3$, $\eta_c = 0.4$
1	1.1128%	1.0986%	1.0739%	1.0525%	1.031%
2	2.2208%	2.1505%	2.1018%	2.0606%	1.970%
3	3.2357%	3.1512%	3.0803%	3.0207%	2.929%

From Table II-2, we find that less elastic labor supply (η_u=-0.1, η_c=0.0) generates more marginal excess burden than more elastic labor supply (η_u=0.4, η_c=0.5). This is because, for the same policy change, the less elastic labor supply implies a more efficient base case. So the new tax policy is less efficient for the less elastic labor supply case than for the more elastic case. Similarly, the more elastic labor supply yields a smaller marginal excess burden, because the more elastic labor supply implies less efficient labor taxation (*i.e.*, an inferior base case). Therefore, for the same magnitudes of policy change, it will generate a smaller marginal excess burden. In other words, when labor supply is more elastic, a reduction in the labor tax rate is more welfare enhancing. Note that, according to the sensitivity test, results about the labor-supply elasticity, we find that the magnitudes of the differences between each marginal excess burden across the different labor-supply elasticity are relatively tiny, because the income elasticity of each test is fixed at –0.1. This result is consistent with the standard tax theories, so that we can conclud

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conclude this simulation model is reliable in terms of the labor supply elasticity. The graphical explanation is presented in Figure II-2.

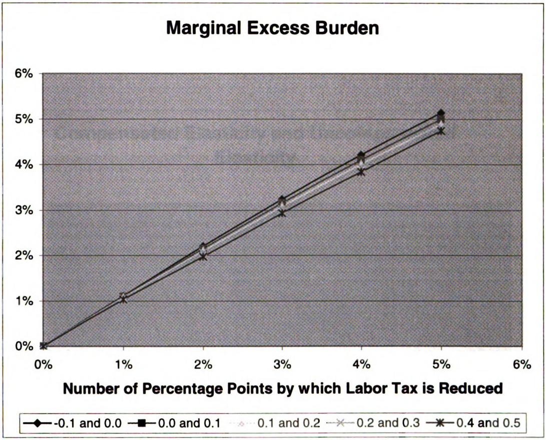

Figure II-2. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Labor-Supply Elasticity (η)

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In order to analyze the independent effect of compensated elasticity (η_c) and the uncompensated elasticity (η_u), I change one elasticity while the other elasticity is held constant. The sensitivity test results show that the simulation results are more sensitive to the change of the compensated elasticity than the change of the uncompensated, since in the differential analysis, the compensated elasticity is more important than the uncompensated elasticity[17].

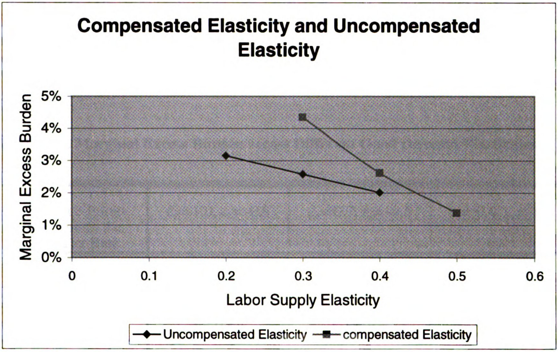

Figure II-3. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity[18]

[17] See Ballard (1990).

[18] For the test of uncompensated elasticity, the compensated elasticity is fixed at 0.5, for the test of compensated elasticity the uncompensated elasticity is set to 0.2. The labor tax reduction is 1 percentage point.

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D-(2). Sensitivity Analysis with respect to the Good Demand Elasticity (ε)

Since I assumed the dirty good as an energy-related polluting good, such as coal and oil, by the characteristic of these goods, the own-price elasticity of the good is relatively small[19]. As mentioned before, the suggested values for elasticity of the energy related polluting good is –1.0 to –0.1. So in this analysis, the test range for the uncompensated elasticity (ε_u) is –1.0 through –0.4, and the range is –0.9 through –0.1 for the compensated elasticity (ε_c). During the test, the labor-supply elasticities are fixed at their central values, 0.1 for the uncompensated elasticity (η_u), 0.2 for the compensated elasticity (η_c). The result of the test is summarized in Table II-3 below.

Table II-3. Marginal Excess Burden across Different Good Demand Elasticities (ε)

Percentage-Point-Reduction in the Labor Tax Rate	ε_u=-1.0, ε_c= -0.8	ε_u=-0.7, ε_c= -0.5	ε_u=-0.4, ε_c= -0.2
1	1.8263%	1.0739%	0.3565%
2	3.6679%	2.1018%	0.6836%
3	5.5177%	3.0803%	0.9818%

From Table II-3 above, we find that a larger demand elasticity yields a larger marginal excess burden than that of a smaller demand elasticity. This is because the tax on the dirty good is less efficient when demand for the dirty good is more elastic (ε_u=-1.0,

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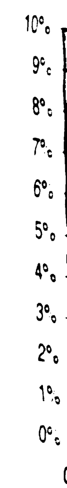

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[9] An ex

ε_c= -0.8) than when the demand is less elastic (ε_u=-0.4, ε_c= -0.2). In other words, since the goods-demand elasticity is associated with the efficiency of the revised case, more elastic demand implies a revised case that is inferior relative to the case of less elastic demand. So for the same base case, a tax on the less elastic demand (more efficient) yields a smaller marginal excess burden than that of a tax on a good that is more elastic (less efficient).

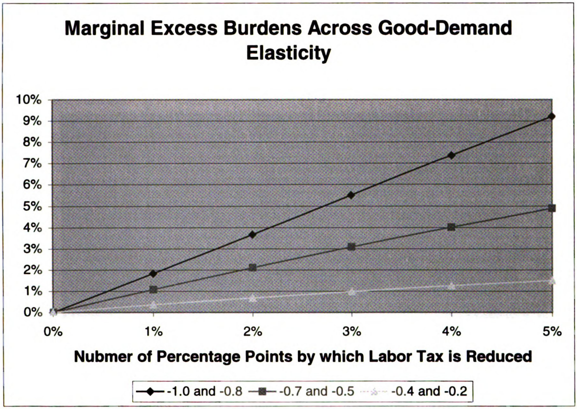

Figure II-4. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Goods-Demand Elasticity (ε)

[19] An excellent review about the demand elasticity of energy good is provided in Nordhaus (1997).

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To see the independent effect of the compensated elasticity (ε_c) and the uncompensated elasticity (ε_u), I change one elasticity while the other elasticity is held constant. As in the sensitivity tests for the labor-supply elasticity, the simulation results are more sensitive to the change of compensated elasticity than the change of uncompensated, since the compensated elasticity is more important than the uncompensated elasticity in the differential analysis.

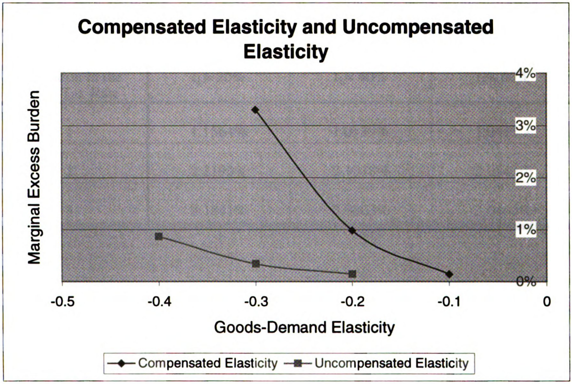

Figure II-5. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity[20]

[20] For the test of the compensated good demand elasticity, I fix the uncompensated elasticity to –0.4. For the uncompensated elasticity test, I set the compensated elasticity to –0.1. The labor tax reduction is 1 percentage point.

D-(3). Sensitivity analysis with respect to the Initial Tax Rates (t_L)

During the simulations, I set the initial tax rates on the labor income to 40% (t_L=0.4). In this subsection, I will report how the simulation results are affected by the level of the initial tax rate on the labor income. The test range on the initial labor tax rate is 20 to 60 percent. The test results are summarized in the Table II-4. Note that the key elasticities are set to their central values.

Table II-4. Marginal Excess Burden across Different Initial Labor Tax Rates

Percentage-Point-Reduction in the Labor Tax Rate	t_L= 20%	t_L= 40%	t_L= 60%
1	1.1564%	1.0739%	1.0415%
2	2.2193%	2.1018%	2.0543%
3	3.1841%	3.0803%	3.0463%

According to the simulation results in Table II-4, we find that a larger initial tax rate generates a smaller marginal excess burden than a smaller initial tax rate on labor income. By assumption, the only distortionary initial tax in this economy is the tax on the labor income. So the initial labor tax rate decides the overall degree of tax distortion of the tax system. When the labor income tax rate is high (t_L= 60%), the tax system is much more distorted than when the labor income tax rate is low (t_L= 20%). Thus for the same magnitude of the policy change, the case of higher initial labor tax rate yields a smaller efficiency cost than the case of lower initial labor tax rate. In other words, the environmental tax reform generates the smaller marginal excess burden when the initial labor t

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labor tax rate is higher. These results for the initial tax rate are similar to the results for the labor supply elasticity, because they are closely related with the condition of the base case. The more efficient base case is correlated with the lower labor-tax rate and smaller labor-supply elasticity, and the less efficient base case is associated with the higher labor-tax rate and the larger labor-supply elasticity. Thus the sensitivity test results in this subsection are similar to the results for those of the labor-supply elasticity. This idea is graphically explained in the figure II-6.

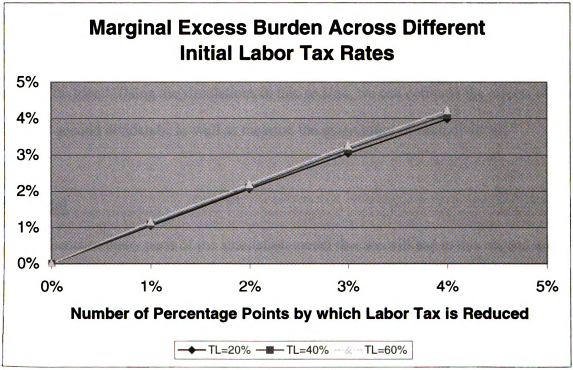

Figure II-6. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Initial Labor Tax Rate (t_L)

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II-2. Homothetic Utility Function with Environmental Externality Factor

From the simulations in the previous section (II-1), we get the result that there is no second dividend of the environmental tax reform, under a variety of reasonable values of the key parameters. Consequently, the simulation results support the idea of Bovenberg and de Mooij (1994). However, as mentioned earlier, the magnitudes of the marginal excess burden of the environmental tax reform are relatively small, so it is a good idea to perform simulations with an explicit environmental externality factor, so that we can measure the first dividend. Thus, in this section, we will perform simulations that contain the effect of the environmental externality, and measure the magnitudes of the first dividend. Using the simulations in this section, we can compare the effects of the first and second dividends, as well as measure the magnitudes of each dividend.

A. Model

Because many parts of the simulation model that we will use in this section are the same as in the previous section, here, we will describe only the critical differences between the two models.

To build a model that considers the first dividend, while maintaining the other critical assumptions, we add environmental damage to the CES function that was used before. The utility function is:

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$$(II-24) \qquad U=\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}+\Pi D$$

where σ is the elasticity of substitution between leisure (l) and the composite good X, β is a weighting parameter, and Π is the marginal environmental damage from the dirty good consumption. Since we are modeling a negative externality, we assume that $\Pi<0$.

We assume that the consumer does not take into account the adverse effect of the dirty good consumption, following the assumptions of Bovenberg and de Mooij (1994). So the consumer's choices of leisure and consumption will not be affected by the environmental damage factor (ΠD). Therefore, the rest of the algebraic processes are exactly the same as previous section ((II-6) to (II-23)). In this model, including the environmental externality factor into the utility function only affects the consumer's welfare level and the measuring of the marginal excess burden of the tax reform.

B. Simulation Methods

Using the same techniques as we used in the previous section (II-1), we will investigate the policy-induced change in the consumer's welfare, along with the marginal excess burden of the new tax system. Again, in the base case, the labor tax is the only tax collected by the government in this economy, and in the revised case, a portion of the labor tax is replaced by an environmental tax, in a revenue-neutral manner. In the base case, the labor tax rate is 40 percent, and in each revised case, the labor tax rate is reduced by one percentage point and replaced with an environmental tax.

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In the central-case simulation, the values for the key elasticities are η_u (uncompensated labor-supply elasticity) =0.1, η_c (compensated labor-supply elasticity) =0.2, ε_u (uncompensated good demand elasticity) =-0.7, and ε_c (compensated good-demand elasticity) = -0.5.

Since the main purpose of this simulation is to investigate the first dividend, it is very important to choose the value for the environmental damage, which is suitable for this simulation model. There are several approaches[21] to estimating the adverse effect of the dirty good consumption, but in this research I will use 'the value of GDP loss' from the polluting good consumption as the environmental externality, because it is logically fit to this simulation model. Many studies suggest that the loss of GDP from the adverse effect of environmental externality is about 1 percent to 5 percent of GDP[22]. So in the central-case simulations, I will use a loss of 3 percent of GDP as the environmental externality. Later in the sensitivity analysis, I will report the results of sensitivity tests with a variety of different values of the environmental damage within the reasonable range.

C. Simulation Results

According to the central-case simulation results, the consumer is better off as a result of the environmental tax reform. The direct environmental benefit (the first dividend) outweighs the negative tax-interaction effect, so that the marginal excess burden of the tax system is actually negative.

[21] The basic idea of those methods is evaluating the direct pollution damages or amenity reductions implied by the worsened quality of the resource (*e.g.*, Hedonic pricing, and Travel cost techniques). For more detailed approaches, please see Roger Perman, Yue Ma, and James McGilvray (1996), pp. 340-344.
[22]The complete comparison is made by Boero, G., Clarke, R., and Winters, L.A. (1991).

As in the previous simulation, there is still no (positive) second dividend of the environmental tax reform. However, if we consider both dividends[23], the environmental tax reform could generate an overall welfare gain. The implication of this result is, even though there is no second dividend of the environmental tax reform, the claim of externality control theory is still effective. More detailed simulation results are summarized in the Table II-5.

Table II-5. Simulation Results of the Central Case

Labor Tax Rate in the Revised Case	Environmental Tax rate	Marginal Excess Burden
0.39	0.0778	-4.6685%
0.38	0.1612	-3.4784%
0.37	0.2506	-2.3391%

Table II-5 shows that the schedule of the necessary environmental tax rates is the same as before (refer to the Table II-1), because adding the environmental externality does not upset the equilibrium conditions of the model. Instead, it affects the consumer's utility level and the measurement of the marginal excess burden of the tax reform.

Compared to the results of the previous simulations, we find that the overall efficiency of the economy is enhanced, because the environmental tax reform yields a negative marginal excess burden. When we reduce the labor tax rate from 40 percent to

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See Boero *et al*, (1991), Table 12.11

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39 percent, the marginal excess burden is –4.66%, similarly, when we reduce the labor tax rate from 40 percent to 37 percent, the marginal excess burden is –2.34%.

From the results of the efficiency gain, we can infer the fact that the consumer actually experiences a positive welfare gain, because the calculation of the marginal excess burden reflects the consumer's welfare change (refer to the equation II-23).

However, as the magnitude of the policy change is increased, the marginal excess burden of the tax reform is increased, and finally becomes positive. Corresponding to this change, we can infer that the consumer experiences a welfare loss as a result of the larger policy change. So in summary, from this central case simulation, we find a fact that for the small policy change, the environmental tax reform enhances overall efficiency, but for the larger policy change, the policy actually worsens the tax efficiency.

The reason that we get this result is, for the relatively smaller policy changes, the positive environmental effect (first dividend) is large enough to overcome the negative tax-interaction effect (second dividend). Thus, overall, the tax reform improves the consumer's welfare. For the larger policy changes, the negative tax interaction effect (second dividend) outweighs the positive environmental effect (first dividend), because the tax distortion of the environmental tax is increasing rapidly. Therefore, the tax reform degrades the consumer's welfare level when the policy change is sufficiently large.

This fact becomes clearer, by the side-by-side comparison between the first dividend (environmental effect) and the second dividend (tax interaction effect).

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[23] Since the consumer does not take into account the adverse effect of the dirty good consumption, the consumer's behavior is not changed at all. Thus, in this sense, it is relevant to consider that the total effect is consisted with first dividend and second dividend.

Table II-6. Comparison of the first and second dividend on Marginal Excess Burden

	Marginal Excess Burden		
Number of Percentage points by which labor tax is reduced	From Environmental Effect (First Dividend)	From Tax Interaction Effect (Second Dividend)	Total
1	-5.74%	1.07%	-4.66%
2	-5.58%	2.10%	-3.47%
3	-5.41%	3.08%	-2.33%
4	-5.24%	4.00%	-1.23%
5	-5.10%	4.88%	-0.21%
6	-4.94%	5.71%	0.76%
7	-4.79%	6.49%	1.69%

Note that, it seems that the size of the first dividend does not rising over the simulations, but actually the first dividend itself does rise. This is because that the marginal excess burden calculation involves a comparison with the amount of revenue that is shifted, and that is also rising.

By the comparison above, we can summarize the simulation results of this section.

① The environmental effect (the first dividend), by itself, is *positive.*

② The tax interaction effect (the second dividend) is *negative*, in this homothetic case.

③ The net effect depends on the relative magnitudes of the two effects. Thus, the net effect can be either positive or negative.

These results are illustrated in the following graph.

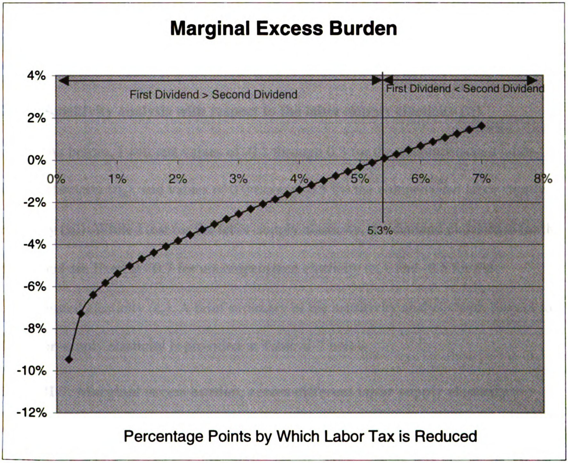

Figure II-7. Marginal Excess Burden by the Environmental Tax Reform

D. Sensitivity Analysis

In this section, I will report the results of sensitivity analysis with respect to the two key elasticities of the model-the labor-supply elasticity (η) and the demand elasticity for the dirty good (ε), the initial tax rate on the labor income, and the level of environmental damage (Π). During the sensitivity tests for the elasticities, as usual, I will fix one elasticity while changing the other one.

D-(1). Sensitivity analysis with respect to the labor-supply elasticity (η)

As before, I will test values of -0.1 through 0.3 for the uncompensated labor-supply elasticity (η_u), and values of 0.0 through 0.5 for the compensated labor supply elasticity (η_c). While I test for the labor-supply elasticity, the demand elasticities for the dirty good are fixed at –0.7 for uncompensated elasticity (ε_u), and -0.5 for the compensated elasticity (ε_c). A brief summary of the sensitivity analysis with respect to the labor-supply elasticity is provided in Table II-7 below.

Table II-7. Marginal excess burden, across different labor supply elasticity (η)

Percentage-Point-Reduction in the Labor Tax Rate	η_u = -0.1, η_c = 0.0	η_u = 0.0, η_c = 0.1	η_u = 0.1, η_c = 0.2	η_u = 0.2, η_c = 0.3	η_u = 0.3, η_c = 0.4
1	-4.141%	-4.413%	-4.668%	-4.902%	-5.069%
2	-2.930%	-3.212%	-3.478%	-3.719%	-3.913%
3	-1.771%	-2.064%	-2.339%	-2.586%	-2.803%

In Table II-7, for a one-percentage-point labor tax reduction, the marginal excess burdens are all negative, which means the tax reform indeed yields an overall welfare again. According to the results, inelastic labor supply (η_u=-0.1, η_c=0.0) generates a smaller efficiency gain than does elastic labor supply (η_u=0.3, η_c=0.4). This is because inelastic labor supply implies a more efficient base case. Thus, for the same magnitude of tax reform, inelastic labor supply is associated with a smaller efficiency gain (or a larger efficiency loss) than elastic labor supply. Note that we find that the magnitudes of the differences between each marginal excess burden across the different labor-supply elasticity are relatively small, because the income elasticity of each test is fixed at –0.1.

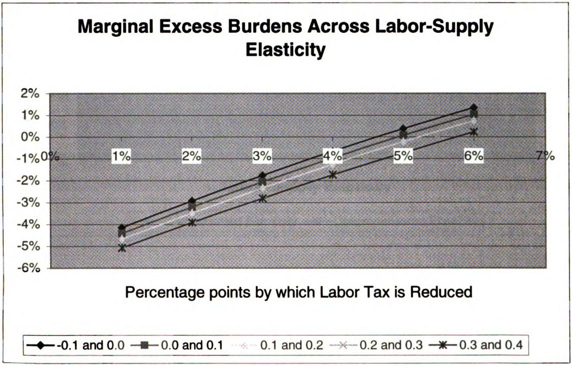

Figure II-8. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Labor-Supply Elasticity (η)

Also, the results of this sensitivity test show that the simulation results are more sensitive to the change of compensated elasticity (ηc) than the uncompensated elasticity (η_u), since, in this kind of policy change (differential analysis), the compensated elasticity is more important.

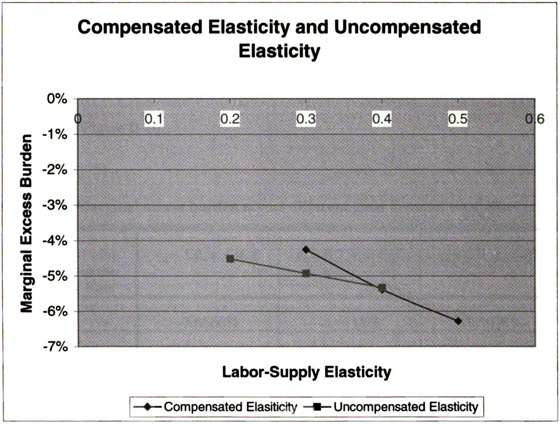

Figure II-9. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity[24]

[24] For the test of uncompensated elasticity, the compensated elasticity is fixed at 0.5, for the test of compensated elasticity the uncompensated elasticity is set to 0.2. Labor tax reduction is 1 percentage point.

D-(2). Sensitivity Analysis with respect to the Goods Demand Elasticity (ε)

The test range for the elasticity of the dirty good (good D) is from –1.0 to -0.1, because most of the studies about demand for the polluting good suggest that the reasonable range of the elasticity of the dirty good is quite small. Here, in this test, the test range for the uncompensated elasticity (ε_u) is –1.0 through –0.4, and the range is –0.9 through –0.1 for the compensated elasticity (ε_c). During the tests, the labor-supply elasticities are fixed at 0.1 for the uncompensated elasticity (η_u), and 0.2 for the compensated elasticity (η_c). The result of the test is briefly summarized in Table II-8 and illustrated in Figure II-10.

Table II-8. Marginal excess burden across different good demand elasticities (ε)

Percentage-Point-Reduction in the Labor Tax Rate	ε_u=-1.0, ε_c= -0.8	ε_u=-0.7, ε_c= -0.5	ε_u=-0.4, ε_c= -0.2
1	-7.6666%	-4.6711%	-1.5978%
10	11.3067%	4.1703%	0.9498%

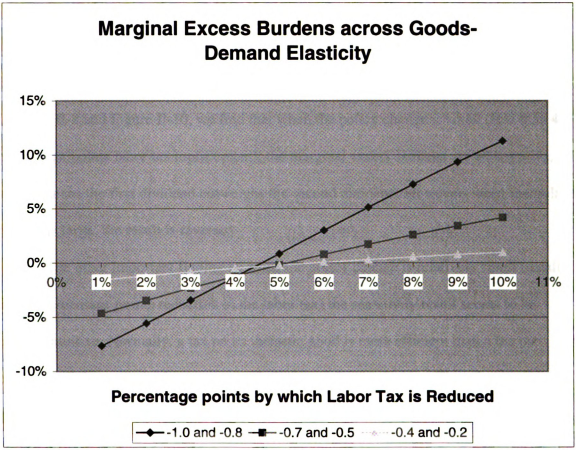

Figure II-10. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Goods-Demand Elasticity (ε)

From Table II-8 and Figure II-10, we find a couple of important facts. When we replace the labor tax with the environmental tax, for the smaller policy changes, the direct environmental benefit (first dividend) is larger than the negative tax-interaction effect (second dividend). So in such a case, the consumer experiences a welfare gain, and economic efficiency is enhanced. However, for the larger policy changes, the negative tax-interaction effect dominates the environmental benefit, because the tax distortion from dirty good taxation is increased, and the marginal excess burden becomes positive. In Table II-8 and Figure II-10, we find that when the policy change is small (less than 4 percentage points labor tax replacement), the marginal excess burdens are all negative, which means the first dividend outweighs the second dividend. However, when the policy change is large, the result is reversed.

The other important finding is, when the policy change is relatively small (smaller then 4 percentage points reduction in the labor tax) the sensitivity result seems to be counterintuitive. Normally, a tax on an inelastic good is more efficient than a tax on elastic good, because the former has a relatively smaller tax burden. Therefore, we generally expect that tax switching to an inelastic sector is superior to tax switching to an elastic sector in terms of tax efficiency. However, an interesting result of this test is that unlike the sensitivity test results of previous section, the efficiency gain (a negative marginal excess burden) in the inelastic-demand case (ε_u=-0.4, ε_c=-0.2) is smaller than the efficiency gain in the elastic case (ε_u=-1.0, ε_c=-0.8) when the policy change is relatively small. Since, theoretically the tax on the inelastic good should be more efficient than tax on the elastic good, this result is seemingly counterintuitive.

However, with the environmental externality factor in this model, it is reasonable to get a result like this. When we replace the pre-existing labor tax with an environmental tax, we expect that there are two major effects, the environmental effect (first dividend) and the tax interaction effect (second dividend). For a smaller policy change, the direct environmental benefit (the first dividend) is larger than negative tax-interaction effect (the second dividend). So for smaller policy changes, most of the welfare change comes from the change in dirty good demand, ΔD (=D_{Base} (demand for the dirty good in the base case) – $D_{Revised}$ (demand for the dirty good in the revised case)). This is because the environmental benefit (the first dividend) reflects the change in the dirty-good demand. When the goods-demand elasticity is large ($\varepsilon_u = -1.0$, $\varepsilon_c = -0.8$), the policy-induced demand change for the dirty good, ΔD, is larger relative to the ΔD of the less elastic case ($\varepsilon_u = -0.4$, $\varepsilon_c = -0.2$). Thus, when the goods demand is elastic, the dominant first dividend (*i.e.*, smaller policy change) is magnified, so the environmental tax reform generates a larger efficiency gain. This is why we get seemingly unreasonable results with respect to the good-demand elasticity when the policy change is relatively small.

When the policy change is large, the tax interaction effect (the second dividend) dominates the environmental benefit, because the tax distortion from the environmental taxation is increased. In this stage (larger policy change), the reduction of the dirty good demand, ΔD, becomes less important, since the welfare change largely depends on the second dividend, rather than the first dividend. Thus in this stage, a larger elasticity ($\varepsilon_u = -1.0$, $\varepsilon_c = -0.8$) yields a larger efficiency loss, because tax switching onto the less efficient good generates larger efficiency costs.

Likewise, the results of this sensitivity test show that simulation results are more sensitive to the change of compensated elasticity (ε_c) than the uncompensated elasticity (ε_u). Since in this kind of policy change (differential analysis), tax revenue collections are not changed, the income effects wash out, so the compensated elasticity is more important. This idea is illustrated in Figure II-11.

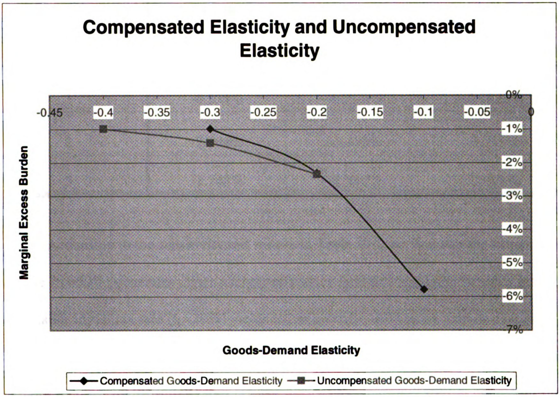

Figure II-11. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity[25]

[25] For the test of uncompensated elasticity, the compensated elasticity is fixed at -0.1, for the test of compensated elasticity the uncompensated elasticity is set to -0.4. Labor tax reduction is 1 percentage point.

D-(3). Sensitivity analysis with respect to the Initial Tax Rates

In this section, I will report the sensitivity test results with respect to the initial tax rates on labor income. As before, the test range for the initial tax rate is 20% to 60%. The sensitivity test results are summarized in the following Table II-9 and Figure II-12.

Table II-9. Marginal excess burden across different Initial Tax Rates (t_L)

Percentage-Point-Reduction in the Labor Tax Rate	t_L= 20%	t_L= 40%	t_L= 60%
1	-4.339%	-4.6711%	-4.8928%
2	-2.992%	-3.480%	-3.783%
3	-1.748%	-2.341%	-2.698%

According to the sensitivity test results in Table II-9, we find that the larger initial tax rate (t_L=60%) generates either a larger efficiency gain or a smaller efficiency loss, and the smaller initial tax rate (t_L=20%) yields either a smaller efficiency gain or a larger efficiency loss. By assumption, the only initial distortionary tax in this economy is the tax on labor income. So the initial labor tax rate decides the overall degree of tax distortion of the tax system in the base case. When the labor income tax rate is high (t_L= 60%), the tax system is much more distorted than when the labor income tax rate is low (t_L= 20%). Thus, environmental tax reform will be more effective (generate a larger efficiency gain or a smaller efficiency loss) when the initial tax system is highly distorted. Similarly, the tax reform will be less effective (yield a smaller efficiency gain or a larger efficiency loss) when the initial tax system is less distorted. If the initial tax system is distorted greatly, then there is more room for the new policy to improve the tax efficiency.

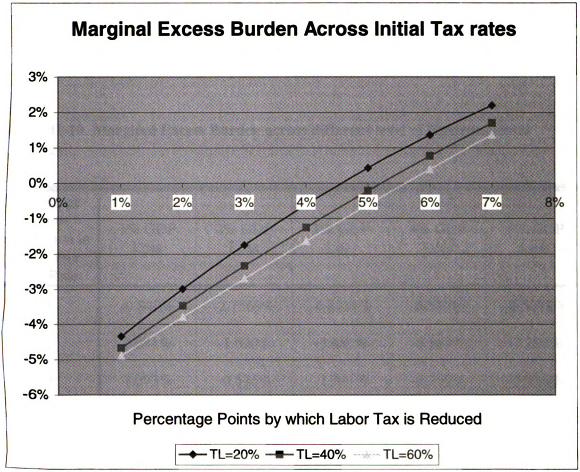

Figure II-12. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Initial Labor Tax Rate (t_L)

D-(4). Sensitivity Analysis with respect to the Environmental Externality (ΠD)

In this section, I will report the results of sensitivity tests with respect to the level of environmental damage. As I declared before, the reasonable range for the environmental damage is about 1 percent to 5 percent of GDP. Thus, in this test, I will perform sensitivity tests with respect to environmental damage, over the range of 1 through 5 percent of GDP. The test results are summarized in the Table II-10.

Table II-10. Marginal Excess Burden across different level of Environmental Damage

Percentage-Point-Reduction in the Labor Tax Rate	1% GDP Loss	2% GDP Loss	3% GDP Loss	4% GDP Loss	5% GDP Loss
1	-0.840%	-2.7569%	-4.6711%	-6.587%	-8.5018%
2	0.241%	-1.620%	-3.481%	-5.343%	-7.203%
3	1.273%	-0.535%	-2.341%	-4.150%	-5.956%

Since the value of the marginal excess burden is closely related to the consumer's welfare change (refer to the equation II-23), the values also reflect the change in the consumer's welfare level. Since the values of marginal excess burden in the Table II-10 are all negative, we find that the consumer actually experiences a welfare gain by the new environmental policy.

In this model (a model that does not have abatement cost), the magnitude of the first dividend largely depends on the size of the environmental externality. When we increase the level of the environmental externality, the consumer gets larger disutility from the externality in the base case. However, in the revised case, the consumer experiences larger benefits from decreasing its dirty good consumption. In this sense, the level of the environmental externality decides the size of the first dividend. As we find in Table II-10, a larger value of the environmental externality yields a larger first dividend.

The important implication of these tests is that even a small consideration of the first dividend could offset the negative second dividend. So although the utility function is homothetic, so that the second dividend is always negative, the environmental tax reform still can improve the consumer's welfare. In other words, even if it is hard to expect a positive second dividend from environmental tax reform, the positive first dividend is still large enough to offset the negative second dividend.

As mentioned before, most of the double-dividend literatures omit (or ignore) the first dividend, because the size of the first dividend is simply uncertain. However, since the uncertainty about the size of the first dividend does not necessarily imply that the first dividend is zero, those kinds of omissions are not desirable. In this sense, a simulation that considers the first dividend is important.

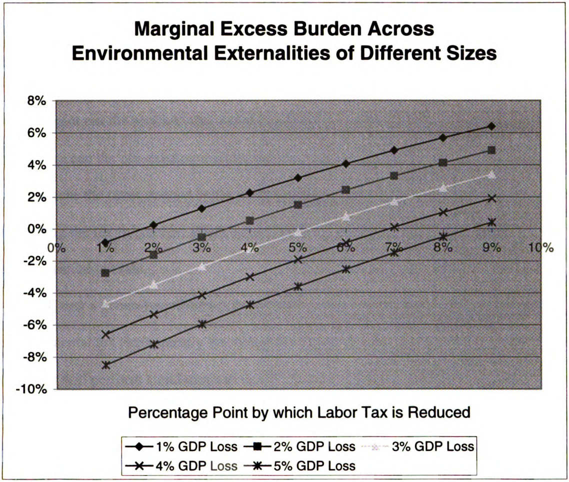

Figure II-13. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Environmental Externality (ΠD)

E. The Optimal Environmental Tax Rate

In this section, we will investigate what is the optimal environmental tax rate under the second-best situation. In the first-best partial equilibrium analysis, the optimal rate of the environmental tax is equal to the marginal external damage of the pollution. This is a classic idea of the externality control theory. However, in a second-best situation, the simple Pigouvian tax theory is inadequate. Most of the general-equilibrium studies point out the problem that partial-equilibrium studies neglect the tax-interaction effect between the pre-existing distortionary tax and the newly introduced environmental tax. Because the taxes interact in the multi-market general-equilibrium situation, neglecting the tax interaction effect causes different results regarding the optimal environmental tax rate.

Using a general-equilibrium framework, several economists find that the optimal environmental tax rate typically lies below the Pigouvian tax, in a second-best world. Here, we will perform simulations to verify whether the earlier general-equilibrium studies are correct. Moreover, we will calculate the optimal environmental tax rate in the second-best world.

According to the classical externality control theory, the optimal environmental tax rate should be equal to the marginal externality. If this reasoning is still applicable to the general-equilibrium situation, then the environmental tax rate that maximizes the consumer's welfare gain should be exactly equal to the marginal external damage. Then in our simulation model, the consumer's welfare change (welfare gain) should be maximized when the environmental tax (t_D) is equal to the assumed marginal external damage (Π). We will fix the important key elasticities to their central values, (η_u=0.1,

η_c=0.2, ε_u=-0.7, ε_c= -0.5.), so that these simulation results can be compared with our other results on this topic.

In the model with a homothetic utility function, the simulation results show that the idea of Bovenberg and de Mooij (1994) about optimal environmental tax rate is correct. As they point out, due to the tax interaction effect, the optimal level of the environmental tax rate is smaller than that of the first-best situation. According to the theory that considers the first best-case, when we use the assumed marginal environmental damage, which is equal to 0.03 (in absolute terms, so $|\Pi| = 0.03$), the optimal level of environmental tax rate that maximizes the consumer's welfare gain is 0.03 (3 %). However, the simulation results show that the consumer's welfare gain is maximized at an environmental tax rate of 0.0274 (2.74%), rather than 0.03 (3%). The graphical illustration is provided in Figure II-14.

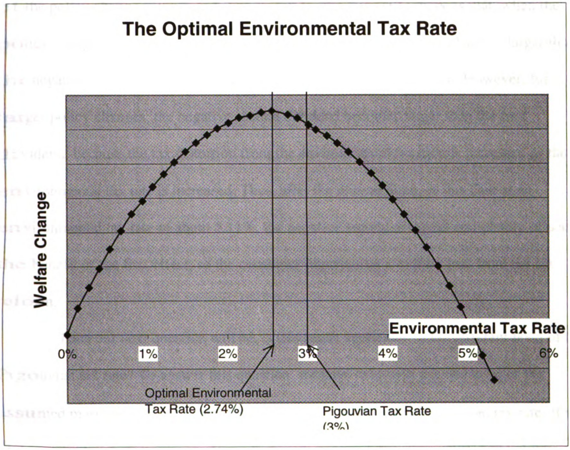

Figure II-14. The Optimal Environmental Tax Rate when the Marginal Environmental Damage is 3% |Π|=0.03

Figure II-14 illustrates the trajectory of the consumer's welfare change, derived by the environmental tax reform. The consumer's welfare change takes the form of inverse-U shape. When the environmental tax rate is small, the consumer experiences a welfare gain. However, after some point, the welfare gain is decreased as the magnitude of the policy change is increased. The reason for the inverse-U shape is that, when the policy change is small, the direct environmental benefit (the first dividend) is larger than the negative second dividend, so the consumer gets a net welfare gain. However, for larger policy changes, the negative second dividend becomes larger than the first dividend, because the tax distortion from the environmental taxation is increased as the environmental tax rate is increased. Thus, after the critical point, in this case at an environmental tax rate of about 5.11%, the negative second dividend completely offsets the benefit of the first effect, so the consumer experiences a welfare loss from the tax reform.

Then our next question will be, is this result applicable to the different level of the Pigouvian tax rate? To answer this question, we have to choose various level of the assumed marginal environmental damage (Π) first, to define the Pigouvian tax rate. If we change the level of the assumed marginal environmental damage to 0.05 ($|\Pi|=0.05$), then the ideal environmental tax rate in the first-best situation (Pigouvian tax) is 5%. In other words, the consumer's welfare gain should be maximized when the environmental tax reaches to 5%. However, the simulation result shows that the consumer's welfare gain reaches its maximum point at 0.046 ($t_D = 4.6\%$), rather than 0.05 ($t_D = 5\%$). This pattern is quite consistent across different levels of the Pigouvian tax. The simulation results for different values of the marginal environmental damage summarized in Table II-11.

Table II-11. The optimal environmental tax rate, under the first best and second best world

Marginal Environmental damage(in absolute term)	The optimal environmental tax rate under first-best world (Pigouvian Tax)	The optimal environmental tax rate under the second-best world	The Largest t_D, that the first dividend is larger than the second dividend ($\Delta W>0$)
$\Pi=0.03$	$t_D = 3\%$	$t_D = 2.74\%$	$t_D = 5.11\%$
$\Pi=0.05$	$t_D = 5\%$	$t_D = 4.60\%$	$t_D = 9.12\%$
$\Pi=0.07$	$t_D = 7\%$	$t_D = 6.18\%$	$t_D = 13.19\%$
$\Pi=0.10$	$t_D = 10\%$	$t_D = 9.40\%$	$t_D = 19.02\%$

Parry (1995) measures the optimal environmental tax rate, allowing the tax-interaction effect in general-equilibrium simulations. He estimates that the optimal environmental tax rate is in the range of 63% to 78% of the Pigouvian tax rate. Bovenberg and Goulder (1996) calculate that the estimated optimal environmental tax rate is about 88% to 93% of the assumed marginal environmental damages, using the computational general-equilibrium simulations. In our model, the estimated value for the optimal environmental tax rate is about 89% to 94% of the Pigouvian tax rate. This result is broadly similar to the suggested values of the previous studies.

In summary, by the simulations in this section, we reach the conclusion that the optimal environmental tax rate under the second-best setting lies below the Pigouvian tax rate because of the tax-interaction effect. This conclusion confirms the argument of Bovenberg and his co-authors. However, this result (and other results derived in this chapter), may depend on the assumption of homothetic utility. We relax that assumption in the next chapter.

Chapter III

Simulations with Non-homothetic Utility

In this chapter, I will perform simulations with a simple general-equilibrium model, using a different functional-form assumption from that of the previous chapter. As I mentioned before, the results of Bovenberg and de Mooij (1994) about the double dividend of environmental tax reform come mainly from the rather artificial functional assumption. To demonstrate this idea, I will relax one key assumption that Bovenberg and de Mooij used. So, in this section, we consider a model with a utility function that is separable between goods and leisure, as before. However, the inner nest of the utility function is assumed not to be homothetic.

In the first subsection of this chapter, I will review "the Ramsey Rule" more closely to show why the functional assumptions are so critical for the conclusions that Bovenberg and de Mooij made. Then in the following two subsections (III-2 and III-3), I will perform simple simulations with the non-homotheticity assumption using two different utility functions, one with an explicit environmental externality and one without an environmental externality.

III-1. A Review of the Ramsey Rule[26]

In this section we will investigate why the functional assumptions are so critical in getting the conclusion of the Bovenberg and de Mooij. We begin by reviewing the "Ramsey Rule" of optimal commodity taxation.

The government's problem is to maximize the consumer's utility with the constraint of the tax revenue. So the mathematical expression of the government will be the Lagrangan function below,

$$(III-1) \qquad \pounds = U(X_0, X_1, \dots, X_m) + \mu\left(\sum_{i=1}^{m} t_i X_i - T\right) \quad ,$$

where $U(X_0, X_1 \dots X_m)$ is the consumer's utility function, X_0 is (untaxed) leisure, T is the revenue requirement, t_i are the tax rates on the m taxed commodities.

The first-order conditions for the government's problem are

$$(III-2) \qquad \sum_{i=0}^{m} \frac{\partial U}{\partial X_i}\frac{\partial X_i}{\partial P_k} + \mu\left(\sum_{i=1}^{m} t_i \frac{\partial X_i}{\partial P_k} + X_k\right) = 0 \qquad for \quad k = 1, \dots, m$$

where P_k is the gross-of-tax price paid by the consumer for good k.

By the assumption that producer prices are fixed,

$$(III-3) \qquad \frac{\partial X_i}{\partial P_k} = \frac{\partial X_i}{\partial t_k}$$

[26] Note that this section closely follows Sandmo (1976).

Meanwhile, the consumer's problem is

Maximize U(X_0, $X_1, \ldots,$ X_m), Subject to the budget constraint, $\sum_{i=0}^{m} P_i X_i = 0$

So the Lagrangean function for the consumer will be

$$(III-4) \qquad £ = U(X_0, X_1, \ldots, X_m) + \lambda(\sum_{i=0}^{m} P_i X_i)$$

The consumer's first-order conditions are,

$$(III-5) \qquad \frac{\partial U}{\partial X_i} = \lambda P_i \qquad for \quad i = 0, \ldots, m$$

Substituting (III-5) into (III-2), we have

$$(III-6) \qquad \lambda \sum_{i=0}^{m} P_i \frac{\partial X_i}{\partial P_k} + \mu\left(\sum_{i=1}^{m} t_i \frac{\partial X_i}{\partial P_k} + X_k\right) = 0 \qquad for \quad k = 1, \ldots, m$$

When we differentiate the consumer's budget constraint with respect to the t_k, we have

$$(III-7) \qquad \sum_{i=0}^{m} P_i \frac{\partial X_i}{\partial P_k} + X_k = 0$$

After rearranging (III-7), we have

$$(III-8) \qquad \sum_{i=0}^{m} P_i \frac{\partial X_i}{\partial P_k} = -X_k$$

If we substitute (III-8) into (III-6), we have

$$(III-9) \qquad -\lambda X_k + \mu\left(\sum_{i=1}^{m} t_i \frac{\partial X_i}{\partial P_k} + X_k\right) = 0 \qquad for \quad k = 1,\ldots,m$$

After rearranging (III-9), we have equation (III-10):

$$(III-10) \qquad \sum_{i=1}^{m} t_i \frac{\partial X_i}{\partial P_k} = \left(\frac{\lambda - \mu}{\mu}\right) X_k \qquad for \quad k = 1,\ldots,m$$

Since the λ and μ are the Lagrange multipliers, the first term of right-hand side $\left(\frac{\lambda - \mu}{\mu}\right)$ is constant, we can represent it by A. Also, if we divide both sides by X_k, we have the key equation (III-11),

$$(III-11) \qquad \frac{\sum_{i=1}^{m} t_i \frac{\partial X_i}{\partial P_k}}{X_k} = A \qquad for \quad k = 1 \ldots m$$

A few additional manipulations allow us to infer the Ramsey Rule: the optimal set of taxes will lead to the same proportion of reduction in compensated demand for every commodity, *when no restrictions are placed on the form of the utility function.* Equation

(III-11) does not necessarily imply that uniform taxation is optimal. However, when we impose the condition "$\frac{\partial X_i}{\partial P_k} = \frac{\partial X_k}{\partial P_i}$ for all i, k", then equation (III-11) becomes,

$$(III-12) \qquad \frac{\sum_{i=1}^{m} t_i \frac{\partial X_k}{\partial P_i}}{X_k} = A \qquad for \quad k = 1...m$$

Equation (III-12) means that the Ramsey result of uniform proportional reduction of demand would be true, so it implies that uniform taxation is optimal.

So, the condition of $\frac{\partial X_i}{\partial P_k} = \frac{\partial X_k}{\partial P_i}$ is critical in deriving the fact that uniform taxation is the optimal for the commodity taxation. Then the next question will be, when will the condition, $\frac{\partial X_i}{\partial P_k} = \frac{\partial X_k}{\partial P_i}$ hold?

From the Slutsky decomposition,

$$(III-13) \quad \frac{\partial X_i}{\partial P_k} = S_{ik} - X_k \frac{\partial X_i}{\partial I}$$

$$(III-14) \quad \frac{\partial X_k}{\partial P_i} = S_{ki} - X_i \frac{\partial X_k}{\partial I}$$

For $\frac{\partial X_i}{\partial P_k} = \frac{\partial X_k}{\partial P_i}$, equation (III-13) should be equal to (III-14). Since it is true that $S_{ik} = S_{ki}$, by Young's theorem, the necessary condition for the $\frac{\partial X_i}{\partial P_k} = \frac{\partial X_k}{\partial P_i}$ is,

$$(III-15) \qquad -X_k \frac{\partial X_i}{\partial I} = -X_i \frac{\partial X_k}{\partial I} \quad .$$

After some manipulations, (III-15) becomes

$$(III-16) \qquad \frac{\partial X_i}{X_i} \frac{I}{\partial I} = \frac{\partial X_k}{X_k} \frac{I}{\partial I}$$

Equation (III-16) states that the income elasticity of good i should be equal to the income elasticity of good k. In other words, the utility function is homothetic. However, the homothetic utility function does not guarantee the uniform taxation is optimal, because, without further conditions on labor supply, the labor supply could affect the choice between good i and good k, through the price changes. Therefore, for uniform taxation to be optimal, we need an additional assumption of utility *separability* between consumption and leisure. Thus, as long as the utility is homothetic and separable, uniform taxation is optimal.

By the way, in the simple static model by Ramsey, since the only endowment of the consumer is time for labor supply, uniformity can be achieved either by taxing all commodities at the same rate, or by having a tax on labor income only. Thus, as long as utility is homothetic and separable, a tax on labor income only is also optimal.

In short, when the goods are homothetic and separable from leisure, and time is the only endowment good, Ramsey-optimal taxes are either a set of uniform taxes on all goods, or a tax on labor income only.

What is the relationship between the Ramsey optimal tax and the conclusion that Bovenberg and de Mooij made? As I mentioned earlier, Bovenberg and de Mooij assumed that the utility function is homothetic and separable, and that time is the only endowment. Moreover, in the theoretical model of Bovenberg and de Mooij, the labor income tax is the only tax in the initial tax system. Therefore, under the assumptions employed by Bovenberg and de Mooij, the initial tax system (before the environmental tax reform) is indeed Ramsey Optimal.

Since the initial tax system is already optimal, definitely, any policy that displaces the economy from its initial situation will make the economy worse off. We have already confirmed this idea in the previous chapter, using a simple simulation model. This idea motivates us to build a new model that relaxes the homotheticity assumption.

We have seen why Bovenberg and de Mooij (1994) inevitably reject the double-dividend hypothesis of environmental tax reform. In the next few subsections, we will perform simulations without the homotheticity assumption, to see how the assumption affects double dividend.

III-2. Non-homothetic Utility Function without Environmental Externality Factor

The simulations in this section focus on the second dividend, abstracting from the first dividend, by excluding any explicit consideration of the environmental externality. Thus, in this section we investigate the second dividend of the environmental tax reform, under the non-homotheticity assumption.

A. Model

To relax the homotheticity assumption of the utility function, we will use a generalized CES utility function in the inner nest.

The generalized CES form is a CES utility function with minimum requirements for consumption of each good. The minimum required consumption of the clean good is C*, and the minimum required consumption of the dirty good is D*. The inner nest of the utility function takes the form

$$\text{(III-17)} \qquad X = \left[\alpha^{\frac{1}{\nu}} (D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} (C-C^*)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}} ,$$

where ν is the elasticity of substitution between discretionary consumption of the dirty good (D-D*) and discretionary consumption of the clean good (C-C*), α is a weighting parameter on the discretionary consumption of the dirty good, D* is the minimum requirement of dirty good consumption, and C^* is the minimum requirement of clean good consumption.

Unlike the ordinary CES utility function, the generalized CES function is not homothetic with respect to the origin, because of the required consumption, C^* and D^*. However, the generalized CES utility function is homothetic with respect to the displaced origin, *i.e.*, D^*,C^*.

The budget constraint for the inner nest shows that the consumer's net money income should be equal to the gross expenditure on the two goods. Thus, the budget constraint for the inner nest is,

(III-18) $$w'L = P_D'D + P_C'C$$

where the prices include taxes, *i.e.*, $P_D' = P_D(1+t_D)$, $P_C' = P_C(1+t_C)$, $w' = w(1-t_L)$.

We build the Lagrangean function with equation (III-17) and (III-18)

(III-19) $$\pounds = \left[\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} + \lambda\,(w'L - P_D'D - P_C'C)$$

The first-order conditions of the choice variables (C,D) are,

$$(III\text{-}20)\qquad \frac{\partial \pounds}{\partial D} = \alpha^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}}(D-D^*)^{\frac{-1}{\nu}} - \lambda P_D = 0$$

$$(III-21)\qquad \frac{\partial \pounds}{\partial C} = (1-\alpha)^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}}(C-C^*)^{\frac{-1}{\nu}} - \lambda P_C = 0$$

After some algebra, we get the Marshallian demands for the dirty good and the clean good:

$$(III-22)\qquad D = \frac{\alpha\{I_X - \Gamma\}}{P_D^{\nu}\Omega} + D^*$$

and

$$(III-23)\qquad C = \frac{(1-\alpha)\{I_X - \Gamma\}}{P_C^{\nu}\Omega} + C^* \quad ,$$

where $\Gamma = P_D' D^* + P_C' C^*$, $I_X - \Gamma$ ($= w'L - P_D' D^* - P_C' C^*$) is discretionary income, *i.e.*, net money income minus mandatory spending on minimum required consumption (D^*, C^*), and $\Omega = \{\alpha P_D^{1-\nu} + (1-\alpha)P_C^{1-\nu}\}$.

Now, let's consider the outer nest of the consumer's utility function.

$$(III-24)\qquad U = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad ,$$

where σ is the elasticity of substitution between leisure (l) and composite good X, and β is a weighting parameter on leisure consumption.

The budget constraint of the outer nest is

(III-25) $$w'T = P_{XD}X_D + w'l + \Gamma \ ,$$

where X_D is the composite consumption out of discretionary income, and P_{XD} is the price of the X_D.

The budget constraint indicates that the consumer's full income can be allocated to the consumption of leisure or to discretionary consumption of goods.

The Lagrangean function for this problem is,

(III-26) $$\pounds = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} + \lambda(w'T - P_{XD}X_D - w'l - \Gamma)$$

The first-order conditions with respect to the choice variables (l,X_D) are

(III-27) $$\frac{\partial \pounds}{\partial l} = \beta^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} l^{\frac{-1}{\sigma}} - \lambda w' = 0$$

$$(III-28) \qquad \frac{\partial £}{\partial X_D} = (1-\beta)^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} X_D^{\frac{-1}{\sigma}} - \lambda P_{XD} = 0$$

After some algebra, we get the Marshallian demands for leisure (l) and discretionary composite goods consumption X_D.

$$(III-29) \qquad l = \frac{\beta \cdot I_D}{w'^{\sigma}\Delta}$$

and

$$(III-30) \qquad X_D = \frac{(1-\beta)\cdot I_D}{P_{XD}{}^{\sigma}\Delta} \quad ,$$

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

The production function is the same as the one that we used in previous chapter. Each industry uses labor as the only input, using linear technology. So the algebra of the production process is exactly the same as equations (II-15) through (II-17) in Chapter II. Also, the government behavior is the same as in Chapter II. That is, the government charges a labor income tax only in the initial situation, and the government will replace a portion of the labor tax with an environmental tax (a tax on the dirty good) in a revenue-neutral manner. The government allocates its expenditure to good C and good D on the basis of the utility function.

The calibration process is somewhat different from the one in the previous chapter. Since we are dealing with a non-homothetic utility function, the calibration process in this chapter involves finding the suitable parameters for the desired level of (D*/D) ratio. Once we get the parameters that are compatible with the desired level of (D*/D), then we are ready to perform the simulations. The comprehensive calibration process will be provided in the appendix.

B. Simulation Methods

In the base case, the labor tax is the only tax to be collected by the government. In the revised case, a portion of the labor tax is replaced by an environmental tax in a revenue-neutral manner. The welfare change is measured by the equivalent variation (E.V.). For the measurement of the welfare costs, we use marginal excess burden (M.E.B.).

In the central-case simulation, I use the same values for the four key elasticities, *i.e.*, $\varepsilon_u = -0.7$, $\varepsilon_c = -0.5$, $\eta_u=0.1$ and $\eta_c=0.2$, and set the base case labor tax rate to 40 percent. We introduce non-homotheticity by setting the ratio of (D*/D) to some positive number. Several studies[27] about the energy demand suggest that it is relevant to think there is a non-zero amount of fixed demand (in the sense of minimum requirement of consumption) for energy goods. According to their argument, some portion of the total demand for the energy related good (which generates the pollution) should be treated as fixed one. Conrad and Schroder (1991) estimate the ratio of (fixed demand / total

[27] Puller and Greening(1999), Gardner and Elkhafif (1998), Baker, Blundell and Micklewright (1989)

demand) of the energy goods, and their measured values of (D*/D) ratio are in the range of 1 percent to 30 percent. In the central-case simulation, I will set the ratio of (D*/D) to 15 percent, and perform sensitivity tests with respect to the values of the ratio (D*/D). For analytical convenience, we assume that the minimum requirement of the clean good consumption (C*) is zero.

C. Simulation Results

The main purpose of this simulation is to demonstrate how the non-homotheticity assumption of the utility function affects the double dividend of environmental tax reform. To concentrate on the second dividend, apart from the first dividend, we exclude the environmental externality factor in the consumer's utility function.

In summary, we get significantly different results from those of Bovenberg and de Mooij (1994). By using a different functional assumption for the consumer's preferences, *i.e.*, relaxing the homotheticity assumption, we get the result that the environmental tax reform improves the consumer's welfare, even abstracting from the first dividend. This result is quite important, since the non-homotheticity assumption upsets the previous theoretical and numerical findings of general-equilibrium studies regarding environmental tax reform.

A brief summary of the key findings in the central-case simulation is given in the Table III-1 below. In the central-case simulation, I fix the desired level of the (D*/D) ratio to 15 percent.

Table III-1. Simulation Results of the Central Case

Labor Tax Rate in the Revised Case	Environmental Tax rate	Marginal Excess Burden
0.39	0.0672	-0.0592%
0.38	0.1386	0.8197%
0.37	0.2144	1.6541%

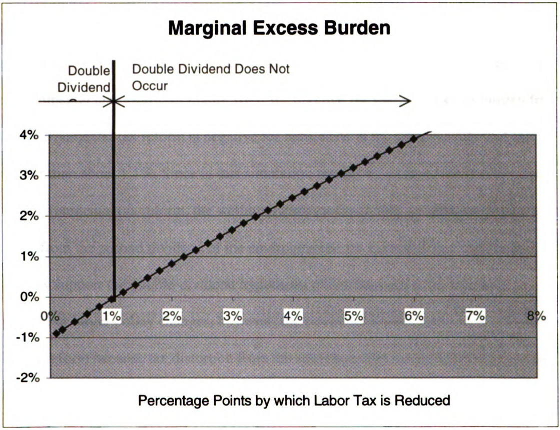

Figure III-1. Marginal Excess Burden by the Environmental Tax Reform when Utility is Non-homothetic.

Because of the narrower tax base, the environmental tax rate that is necessary to make up the revenue loss from a one-percentage-point labor tax reduction is substantially higher than one percent. The tax base of the labor tax is 100 percent of GDP, while the tax base of the environmental tax is about 15 percent of the GDP. So, when the labor tax is reduced from 40 percent to 39 percent, the necessary environmental tax rate to cover the revenue loss is about 6.67 percentage points. The necessary environmental tax rate to cover the revenue loss from the labor tax reduction grows more than proportionally when the magnitude of the policy change becomes larger.

Most importantly, the consumer experiences a welfare gain from the policy change. For a small policy change, the environmental tax reform yields a positive welfare gain for the consumer. Thus the efficiency of the overall tax system is improved by the environmental tax reform. In Figure III-1, we find that the marginal excess burden from the environmental tax reform is negative for reductions in the labor tax rate that are smaller than about 1.1%. Since in this simulation model, we exclude the first dividend of the environmental tax reform, the welfare improvement and the tax efficiency gain come solely from the second dividend of the environmental tax reform. These simulations strongly support the double-dividend hypothesis of environmental tax reform.

For larger policy changes, however, the consumer experiences a welfare loss from the tax reform because tax distortion from the environmental tax becomes larger when the policy change is increased.

Besides Bovenberg and de Mooij, most of the earlier general-equilibrium studies of the double dividend of environmental tax reform made similar conclusions that tend to reject the double-dividend hypothesis, using both theoretical and numerical analysis. Since all of the studies use utility functions that are homothetic and separable, they all reach the same predetermined conclusion on the topic of the double dividend. However, as soon as we relax the homotheticity assumption, we get significantly different simulation results, *i.e.*, the double dividend of the environmental tax reform is possible.

D. Sensitivity Analysis

Here, I will report the results of sensitivity tests with respect to the key parameters: the labor-supply elasticity (η), demand elasticity of the dirty good (ε), level of initial tax rates on the labor income (t_L), and the level of the (D^*/D) ratio.

D-(1). Sensitivity analysis with respect to the Labor-Supply Elasticity (η)

The sensitivity test with respect to the labor-supply elasticity is done for the reasonable range of parameters that is suggested by the related studies. As before, the test range for the uncompensated labor-supply elasticity (η_u) is between -0.1 and 0.3, and the test range for the compensated labor-supply elasticity (η_c) is 0.0 through 0.5. During the sensitivity test for the labor-supply elasticity, the compensated and uncompensated good demand elasticities are fixed at their central values, for definitive results. I set the uncompensated good demand elasticity (ε_u) to –0.7 and I use –0.5 for the compensated good demand elasticity (ε_c). Also, I set the ratio of (D^*/D) to 15 percent during the sensitivity tests with respect to the labor supply elasticity.

Table III-2. Marginal Excess Burden, Across Different Values of the Labor-Supply Elasticity (η)

Percentage-Point-Reduction in the Labor Tax Rate	$\eta_u = -0.1$, $\eta_c = 0.0$	$\eta_u = 0.0$, $\eta_c = 0.1$	$\eta_u = 0.1$, $\eta_c = 0.2$	$\eta_u = 0.2$, $\eta_c = 0.3$	$\eta_u = 0.3$, $\eta_c = 0.4$
1	0.882%	0.445%	-0.0592%	-0.6388%	-1.3120%
2	1.733%	1.309%	0.819%	0.259%	-0.387%
3	2.542%	2.130%	1.654%	1.112%	0.487%

When the labor supply elasticity is small the environmental tax policy generates a positive marginal excess burden from the tax reform, which means that the policy yields gross efficiency costs. However, when the labor supply is elastic (η_u=0.3, η_c=0.4), the environmental tax reform actually generates negative marginal excess burden, which implies the policy enhances the efficiency of the tax system.

This is because a tax on inelastic labor supply is relatively superior to the tax on the elastic labor-supply in terms of the tax efficiency, so the base case of inelastic labor supply is more efficient than the base case of elastic labor supply. In other words, because the inelastic labor supply case has less room to improve the tax efficiency, it yields a smaller efficiency gain, compared to the elastic labor supply case. This result is consistent with standard tax theories, so in this sense, we conclude that this model is robust in terms of the labor-supply elasticity (η).

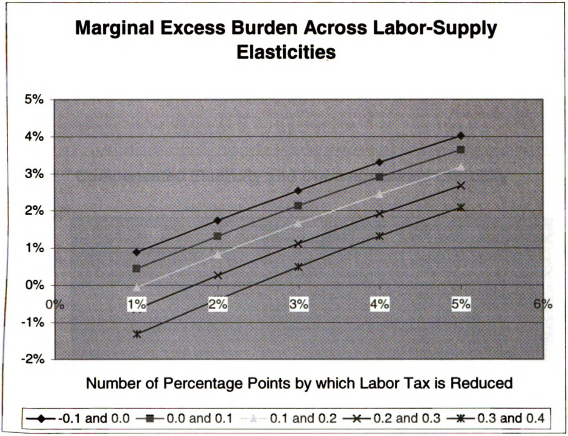

Figure III-2. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Labor-Supply Elasticity (η)

In order to analyze the size of independent effect of compensated elasticity (η_c) and the uncompensated elasticity (η_u), I change one elasticity while the other elasticity is held constant. The sensitivity test results show that the simulation results are more sensitive to the change of compensated elasticity than the change of the uncompensated, since in the differential analysis, the compensated elasticity is more important than the uncompensated elasticity.

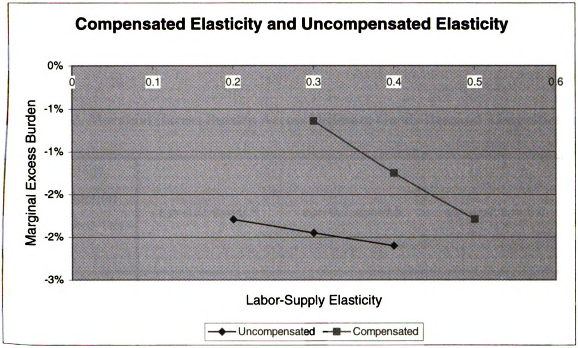

Figure III-3. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity of Labor Supply[28]

D-(2). Sensitivity analysis for the Dirty Good Demand Elasticity (ε)

The sensitivity test of the good demand elasticity will be done for the reasonable range suggested by the related studies. So the test range for the uncompensated elasticity of the dirty good demand (ε_u) is from -1.0 to -0.4, and the range for the compensated elasticity of the dirty good demand (ε_c) is from -0.9 to -0.1. While I test for the dirty good demand elasticities (ε), the uncompensated labor-supply elasticity (η_u) and the compensated labor-supply elasticity (η_c) are fixed at 0.1 and 0.2 respectively. The (D*/D) ratio is held constant at its central value, 15 percent.

The test results are briefly summarized in Table III-3 below.

Table III-3. Marginal Excess Burden Across Different Goods Demand Elasticities (ε)

PercPerentage PointReduction in the Labor Tax Rate	ε_u=-1.0, ε_c=-0.8	ε_u=-0.7, ε_c=-0.5	ε_u=-0.4, ε_c=-0.2
1	0.558%	-0.0592%	-0.6510%
2	2.081%	-0.819%	-0.348%
3	3.581%	1.654%	-0.069%

The test results in Table III-3 above show that the inelastic dirty good demand (ε_u=-0.4, ε_c=-0.2) generates smaller efficiency costs than the elastic dirty good demand (ε_u=-1.0,

[28] For the test of compensated elasticity, the uncompensated elasticity is set to 0.2, and for the test for

ε_c=-0.8). For the same base case (40 percent labor tax) and for the same policy change, switching toward greater taxation of an inelastically demanded good yields a larger efficiency gain than switching to greater taxation of an elastically demanded good. Because a tax on an elastically demanded good is inferior to a tax on an inelastically demanded good in terms of tax efficiency, inelastic demand implies a better revised case, compared to elastic demand.

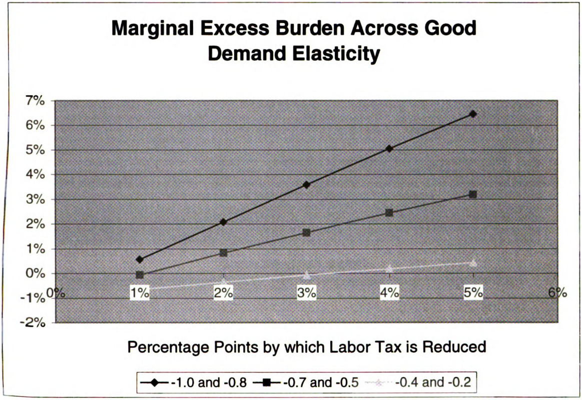

Figure III-4. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Goods-Demand Elasticity (ε)

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uncompensated elasticity the compensated elasticity is fixed at 0.5. Labor tax reduction is 1 percentage point.

The test result for the independent effect of each elasticity is normal, since the simulation results are more sensitive to the compensated goods demand elasticity than to the uncompensated elasticity.

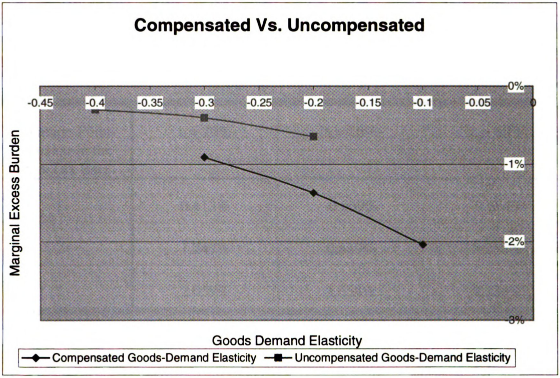

Figure III-5. Efficient Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity of Goods-Demand Elasticity[29]

[29] For the test of compensated elasticity, the uncompensated elasticity is set to -0.4, and for the test for uncompensated elasticity the compensated elasticity is fixed at -0.1. Labor tax reduction is 1 percentage point.

D-(3). Sensitivity Analysis with respect to the Initial Tax Rates

As before, the test range of the initial labor tax rate is over the range from 20 to 60 percent, and other key parameters are set to their central values. The test results are summarized in Table III-4.

Table III-4. Marginal Excess Burden across different Initial Tax Rates (t_L)

Percentage-Point-Reduction in the Labor Tax Rate	t_L= 20%	t_L= 40%	t_L= 60%
1	0.413%	-0.059%	-0.664%
2	1.247%	0.819%	0.278%
3	2.059%	1.654%	1.136%

Table III-4 shows that if the initial tax rate on the labor income is small (t_L= 20%) the environmental tax reform yields a gross cost, because the marginal excess burden of the tax reform is positive. However, when the initial labor tax is higher, the tax reform generates a welfare gain. Since we have assumed that the labor tax is the only distortion of this tax system, the initial level of the labor tax determines the level of tax distortion. If the initial labor tax rate is high, the tax system is much more distorted than when the initial labor tax rate is low. So for the same magnitude of the policy change, because of the larger distortion in the base case, a higher initial labor tax rate generates a smaller efficient cost (or larger efficiency gain) than when labor income is taxed at a low rate.

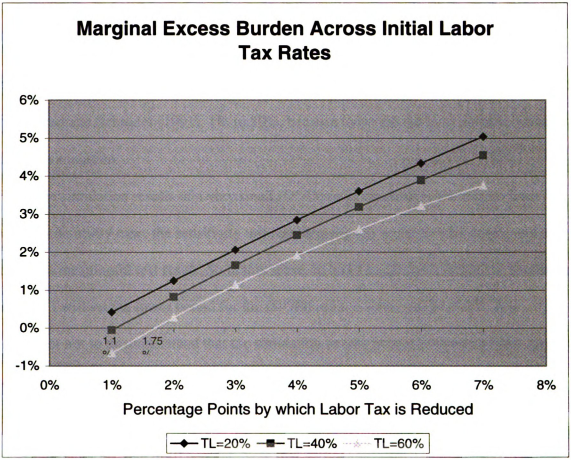

Figure III-6. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Initial Labor tax rates (t_L)

D-(4). Sensitivity tests for the (D*/D) Ratio

The simulation results of this chapter largely depend on the ratio of (D*/D), because the level of the (D*/D) ratio determines the degree of non-homotheticity. For this reason, the sensitivity analysis for the (D*/D) ratio is also very important. The estimated values for the (D*/D) ratio vary widely[30], depending on the characteristic of the good and the specification of the demand. However, in this research, I will use the values estimated by Conrad and Schroder (1991), 1% to 30%, because these are the most suitable values for this simulation.

Since the simulation results of a very small (D*/D) ratio are close to the results from the homothetic utility case, the sensitivity test results using too small (D*/D) ratio could not give us a meaningful test result. So in this sense, in order to get more definitive results, in this test I will set the lower bound for the (D*/D) ratio to 10% instead of 1%. It is important not to misunderstand that the simulation results from homothetic utility case and the results from 1% (D*/D) ratio are same, even though they are close[31]. All the key elasticities are fixed at their central values, *i.e.*, $\varepsilon_u = -0.7$, $\varepsilon_u=-0.5$, $\eta_u=0.1$, $\eta_c=0.2$ and the base case labor tax rate is 40 percent. Note that, to hold the income elasticity of the dirty good demand constant, the level of dirty good demand should be changed. The sensitivity test results are reported in Table III-5.

[30] J. Daniel Kazzoom estimates (D*/D) ratio is 75%~95% with industrial demand, and A.G. Vigdonhik and Makarov measures the (D*/D) ratio as 40%~100% with pooled (Industrial, commercial and residential) data. For detailed explanation refer to "International Studies of the Demand for Energy (1977) edited by William D. Nordhaus.

[31] The actual test values are indeed different between (D*/D)=0 and (D*/D)=1%, however, but the size of the difference is not so large.

Table III-5. Marginal Excess Burden Across Different (D*/D) Ratios

Percentage-Point-Reduction in the Labor Tax Rate	(D*/D) = 10%	(D*/D) = 20%	(D*/D) = 30%
1	0.310%	-0.422%	-1.1274%
2	1.234%	0.416%	-0.378%
3	2.112%	1.203%	0.334%

From the sensitivity test with respect to the (D*/D) ratio, we reach the conclusion that a higher (D*/D) ratio will yield a larger welfare gain. When the ratio of (D*/D) is 10 percent, the environmental tax reform generates gross costs. However, as the ratio increases, the tax reform eventually reduces the overall tax distortion, so that the marginal excess burden becomes negative.

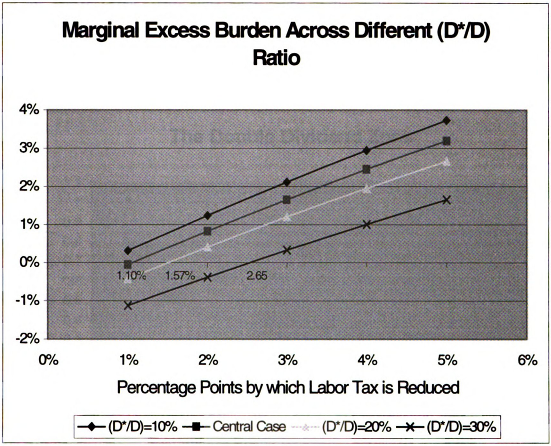

Figure III-7. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Ratio of (D*/D)

During the simulations in this section, we conclude that the double dividend of the environmental tax reform is possible if we relax the homotheticity assumption. So, it is an interesting to analyze the *combinations* of the key parameters, *i.e.*, elasticity and initial tax rate, that yield the double dividend.

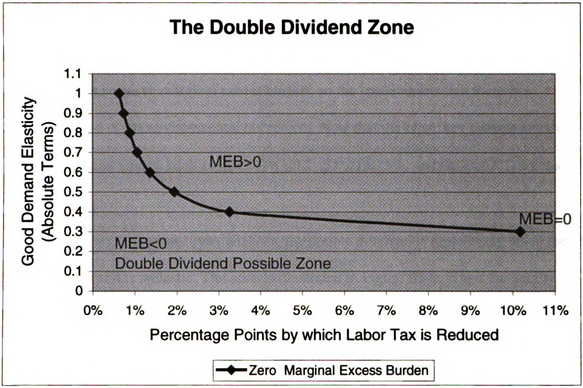

Figure III-8. The Combinations of ε and t_L that yield Double Dividend (Central Case)

Figure III-8 shows the possible combinations of ε and t_L that generate a double dividend of environmental tax reform. The vertical axis stands for the good demand elasticity in absolute terms ($|\varepsilon|$), and the horizontal axis represents the magnitude of the policy change (Δt_L). The downward sloping line is the zero marginal excess burden line, so any combination of ε and t_L that is on the line yields zero excess burden. Points that are above and to the right of the zero marginal excess burden line are associated with positive marginal excess burden, so any point in that space implies no double dividend. Similarly, points that are to the left and below the zero marginal excess burden line are associated with negative marginal excess burden, so the space means that there is a double dividend of the environmental tax reform. Note that the other key parameters are set to their central values, such as η_u=0.1, η_c=0.2, (D*/D)=15%, and the initial labor tax rate is 40%.

As we see in the sensitivity analysis, the double dividend is more likely when the dirty good demand is inelastic. This idea is illustrated in Figure III-8. When the goods-demand elasticity (ε) is large in absolute value, the double dividend is possible only for very small policy changes. However, when $|\varepsilon|$ is small, the range becomes wider. When $|\varepsilon|$=0.3, the double dividend is possible for a reduction in the labor tax rate of more than 10 percentage points. Since the simulation results are very sensitive to the degree of non-homotheticity ((D*/D)), it is interesting to consider a double dividend zone graph with different degree of non-homotheticity.

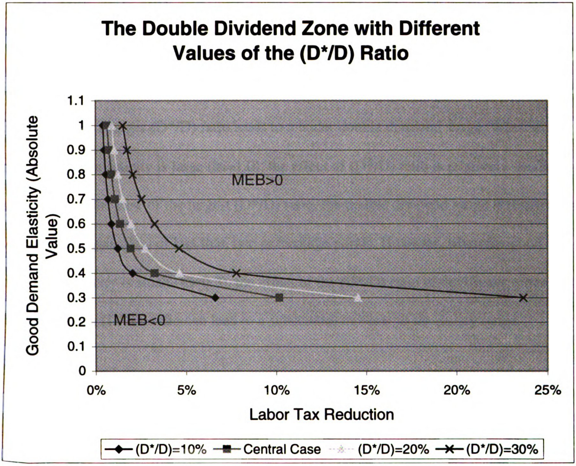

Figure III-9. The Combinations of ε and t_L that yield Double Dividend with (D*/D) Ratio

The interpretation of Figure III-9 is very similar to that of Figure III-8. Each line in the graph represents a set of zero-marginal-excess-burden combinations of the $|\varepsilon|$ and Δt_L, for a given (D*/D) ratio. The area to the left of each line is the double dividend zone, so any combination of $|\varepsilon|$ and Δt_L in the double-dividend zone could make a double dividend.

As we see in the sensitivity analysis, increases in the (D*/D) ratio lead to significant increases in the efficiency gain. Thus for the same level of good demand elasticity ($|\varepsilon|$), a larger (D*/D) ratio leads to a wider double dividend range. When the good demand elasticity is large ($|\varepsilon|=1.0$), the effect of (D*/D) ratio is relatively small, since even in the case of the largest (D*/D) ratio, the double dividend range is restricted to policy changes (Δt_L) of less than two percentage points. However, when the good demand elasticity is small ($|\varepsilon|=0.3$), the effect of the (D*/D) ratio is significant, since an increase in the (D*/D) ratio can lead to a substantial increase in the policy range.

III-3. Non-homothetic Utility Function with Environmental Externality Factor

In the previous section, we found that the double dividend is possible under the assumption of a non-homothetic utility function. The consumer experiences a welfare gain from the environmental tax reform even without the consideration of the first dividend. In this section, I will perform simulations that consider both the first and the second dividend under the non-homotheticity assumption.

A. Model

To include the first dividend of the environmental tax reform into our analysis, we need to add the environmental externality into the utility function.

So the outer nest of the utility function is:

$$(III-31) \qquad U = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} + \Pi \mathrm{D}$$

I assume that the consumer does not take into account the adverse effect of the dirty good consumption. Because of this assumption, the consumer's choice between leisure and consumption as well as the choice between the clean and the dirty good consumption will not be upset at all. Thus we can once again use the algebraic process in the previous section (section 2 of chapter III), without causing any problem. For the detailed information about the simulation model, refer to the equations (III-17) through (III-31).

B. Simulation Methods

Using the same simulation techniques as in the previous section (section II-2), we analyze the consumer's welfare change and the change in the tax efficiency, caused by the environmental tax reform.

As in previous chapter, I will use 'the value of GDP loss' as the environmental externality for this simulation model. Again, in the central-case simulation, I will use 3 percent of GDP loss as the externality, since the estimated range of GDP loss from the adverse effect of polluting good consumption is from 1 percent to 5 percent.

As before, in the base case, the labor income tax is the only tax to be collected by the government in this economy, and in the revised case, a portion of the labor tax is replaced by an environmental tax in a revenue-neutral way. The base-case labor tax rate is 40 percent, and in the each revised case, it is replaced with an environmental tax by 1 percentage point. Table III-6, on the next page, has 2 percentage point and 3 percentage point reductions.

In the central-case simulation, the key elasticities also take their central values, *i.e.*, η_u=0.1, η_u=0.2, ε_u=-0.7 and ε_c=-0.5, and the level of the (D*/D) ratio is set to 15 percent.

C. Simulation Results

The simulation results that consider both first and second dividend at the same time show that the environmental tax reform substantially improves the consumer's welfare and enhances the overall tax efficiency. The welfare gain of the consumer is much larger in this section than in the previous one, which means that the first dividend is positive and important. Also, the gain in tax efficiency becomes larger when we consider both the first and second dividend, compared to the case that considers the second dividend only. Let's look at the brief summary of the central-case simulation results.

Table III-6 Simulation Results of the Central Case

Labor Tax Rate in the Revised Case	Environmental Tax rate	Marginal Excess Burden
0.39	0.0672	-4.9867%
0.38	0.1386	-3.9743%
0.37	0.2144	-3.0074%

The necessary environmental tax rates in the second column of table III-6 are exactly the same as in the table III-1, since the general-equilibrium conditions are not changed at all.

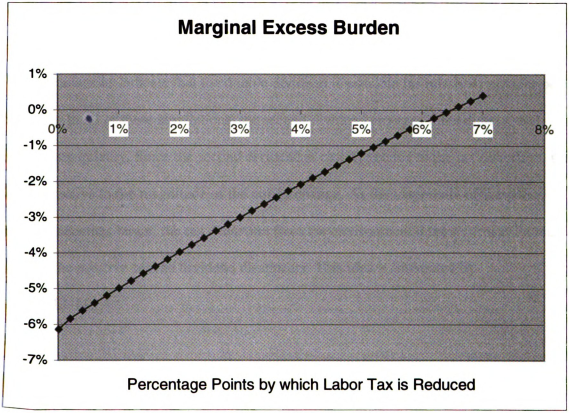

Figure III-10. Marginal Excess Burden by the Environmental Tax Reform (Central Case)

The consumer in this model experiences a welfare gain, through the environmental tax reform. As we saw in the previous section, the consumer's welfare is improved, even without the first dividend of the environmental tax reform. Since the first dividend has a further positive effect on the consumer's welfare, the consumer's welfare gain from the first and second dividend would be larger than the welfare gain from the second dividend only.

The simulations indicate that the double dividend is possible for relatively smaller policy changes. In all of these simulations, the second dividend emerges immediately, and disappears quickly. Since the second dividend is closely related to the tax distortion, it is very sensitive to the magnitude of the policy change. As the magnitude of the policy change becomes larger, the tax distortion from the environmental tax reform is increased, so that the positive second dividend disappears. This idea is illustrated by Figure III-11.

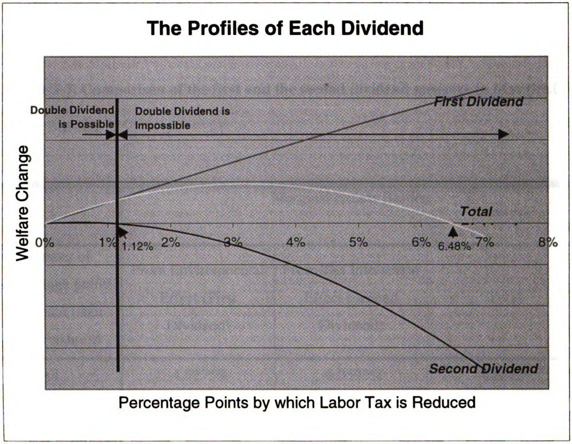

Figure III-11. The Profiles of Each Dividend Measured by the Welfare Change

In Figure III-11, the first dividend is always positive. The second dividend is positive for small policy changes. However, as the size of the policy change is increased, the second dividend becomes negative, because the tax distortion from the environmental tax is increased. For the larger policy change, the total dividend becomes negative, because the negative second dividend is large enough to offset the first dividend.

Table III-7. Comparison of the first and the second dividend measure in Marginal Excess Burden

	Marginal Excess Burden		
Number of Percentage points by which labor tax is reduced	From Environmental Effect (First Dividend)	From Tax Interaction Effect (Second Dividend)	Total
1	-4.9275%	-0.0592%	-4.9867%
2	-4.794%	0.8197%	-3.9743%
3	-4.6615%	1.6541%	-3.0074%
4	-4.5301%	2.4451%	-2.0850%
5	-4.4002%	3.1913%	-1.2089%
6	-4.2720%	3.8932%	-0.3788%
7	-4.1458%	4.5509%	0.4051%

Table III-7 shows the side-by-side comparison between the first dividend and the second dividend, measured in terms of the marginal excess burden of the tax reform. For small policy changes, the marginal excess burden from the second dividend is negative, which means the double dividend is possible. As the magnitude of the policy change is increased, the marginal excess burden from the second dividend becomes positive, so there is no double dividend of environmental tax reform.

Even though the second dividend disappears quickly, the first dividend still dominates the negative second dividend over a fairly large policy change. With the consideration of the first dividend, the simulation results show that environmental tax reform could improve the social welfare for a wide range of the policy change, regardless of the existence of a positive second dividend.

As a conclusion, we can summary the simulation results of this section by

① The environmental effect (the first dividend), by itself, is positive.

② The tax-interaction effect (the second dividend) is positive for the smaller policy change, and is negative for the larger policy change in this non-homothetic case. So the *double dividend of environmental tax reform is possible.*

③ The total effect depends on the magnitudes of each dividend. The total effect is positive for small and medium-sized policy changes, but not for really large policy changes.

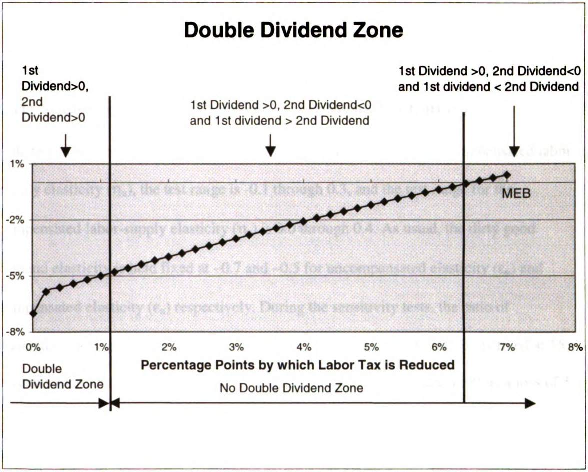

Figure III-12. The Double Dividend Zone

D. Sensitivity Analysis

In this section, I will report the results of the sensitivity tests with respect to the labor-supply elasticity (η), the demand elasticity of the dirty good (ε), the initial labor tax rate (t_L), the level of the externality (Π), and the level of (D*/D) ratio.

D-(1). Sensitivity analysis with respect to Labor-Supply Elasticity (η)

The test range for labor-supply elasticity is same as before. For the uncompensated labor-supply elasticity (η_u), the test range is -0.1 through 0.3, and the test range for the compensated labor-supply elasticity (η_c) is 0.0 through 0.4. As usual, the dirty good demand elasticity is held fixed at –0.7 and –0.5 for uncompensated elasticity (ε_u) and compensated elasticity (ε_u) respectively. During the sensitivity tests, the ratio of mandatory dirty good consumption over demand for the dirty good (D*/D) is fixed at 15 percent. Also, the environmental externality is set to its central value, which is a loss of 3 percent of GDP. The results of the sensitivity tests with respect to the labor-supply elasticity (η) are briefly summarized in Table III-8 below.

Table III-8. Marginal Excess Burden, across different Labor-Supply Elasticity (η)

Percentage-Points-Reduction in Labor Tax Rate	$\eta_u = -0.1$, $\eta_c = 0.0$	$\eta_u = 0.0$, $\eta_c = 0.1$	$\eta_u = 0.1$, $\eta_c = 0.2$	$\eta_u = 0.2$, $\eta_c = 0.3$	$\eta_u = 0.3$, $\eta_c = 0.4$
1	-4.414%	-4.688%	-4.9867%	-5.3337%	-5.7511%
2	-3.438%	-3.679%	-3.974%	-4.314%	-4.720%
3	-2.503%	-2.714%	-3.007%	-3.334%	-3.738%

As in Table III-8, the marginal excess burdens from the one percentage-point replacement are all negative, which implies that the tax reform enhances tax efficiency. For the same policy change, when the labor supply is inelastic (η_u=-0.1, η_c=0.1) the efficiency gain is relatively small, compared to the case of more elastic labor supply (η_u=0.3, η_c=0.4). The reason for this difference is that a tax on an inelastic good is more efficient than a tax on an elastic good. For this reason, the base case with inelastic labor supply is more efficient than the base case with elastic labor supply.

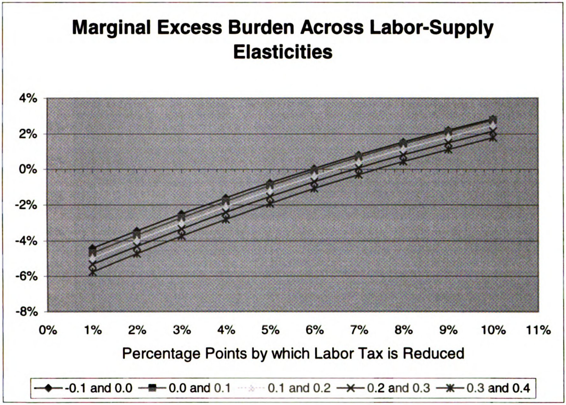

Figure III-13. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Labor-Supply Elasticity (η)

The results of sensitivity test in this subsection show that simulation results are more sensitive to the change of compensated elasticity (ε_c) than to the change of uncompensated elasticity (ε_u). Since in this type of the policy change (differential analysis), the compensated elasticity is more important.

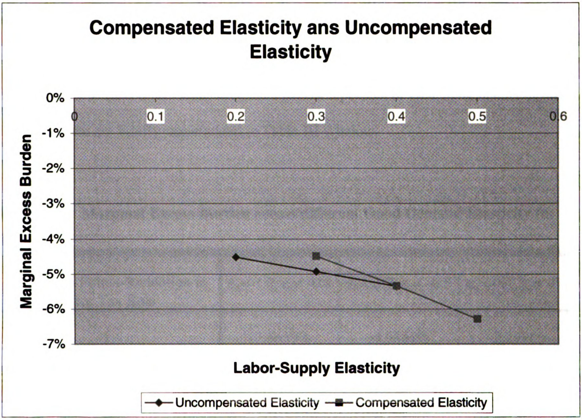

Figure III-14. Efficiency Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity of Labor-Supply Elasticity (η)[32]

D-(2). Sensitivity analysis with respect to the Goods-Demand Elasticity (ε)

The test range for the dirty good demand elasticity (ε) is –1.0 through –0.1. For the uncompensated good demand elasticity (ε_u), the test range is from –1.0 to -0.4 and for the compensated good demand elasticity (ε_c), the test range is from –0.8 to -0.2. As usual, the labor supply elasticities are fixed at 0.1 and 0.2 for the uncompensated labor-supply elasticity (η_u) and the compensated labor-supply elasticity (η_c) respectively. The (D*/D) ratio is fixed at 15 percent during this sensitivity test, and the marginal environmental damage is set to its central value, which is a loss of 3 percent of GDP. The results of the sensitivity test are briefly summarized in Table III-9 below.

Table III-9. Marginal Excess Burden across different Good Demand Elasticity (e)

Percentage-Points-Reduction in Labor Tax Rate	ε_u=-1.0, ε_c= -0.8	ε_u=-0.7, ε_c= -0.5	ε_u=-0.4, ε_c= -0.2
1	-7.6639%	-4.9867%	-2.2996%
10	6.5072%	2.4826%	0.0815%

As in the sensitivity analysis in the previous chapter (Chapter II-2), we have seemingly counterintuitive results with the good demand elasticity, especially for the smaller policy change. Generally, a tax on an inelastic good is more efficient than a tax on an elastic good. Thus, for the same base case, we would expect that switching to a tax on

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[32] For the test of compensated elasticity the uncompensated elasticity is set to 0.1, for the test of uncompensated elasticity the compensated elasticity is set to 0.5. The labor tax reduction is 1 percentage

the dirty good would yield a greater efficiency gain when demand is inelastic (ε_u=-0.4, ε_c=-0.2) than when demand is elastic (ε_u=-1.0, ε_c=-0.8). However, in this test, for the smaller policy change, we get seemingly contradictory results, *i.e.*, the efficiency gain from taxing the dirty good is smaller when demand is more inelastic.

As mentioned before, when the policy change is small, the first dividend of environmental tax reform is larger than the second dividend (either positive or negative). Because the first dividend is closely related to the change in the dirty good demand, the policy-induced welfare change is magnified by the elasticity of the good demand. When the good demand elasticity is large, the demand change in the dirty good (ΔD) is large, which yields a large first dividend (the direct environmental benefit). Thus for the smaller policy change, the larger good demand elasticity yields a larger efficiency gain. This is the reason that we get seemingly counterintuitive results with respect to the good-demand elasticity when the policy change is relatively small.

Since this counterintuitive result mainly comes from the first dividend factor, if the consideration regarding the first dividend is sufficiently small, or close to zero, then we will not have the seemingly contradictory results. (Refer to the sensitivity-test result in previous section D-(2) in Chapter III-2).

When the magnitude of the policy change is large, the welfare effects move in the opposite (more intuitive) direction. For the larger policy change, the tax distortion from the environmental tax reform is increased. In this stage (larger policy change) the direct environmental benefit is relatively less important, because the tax interaction effect

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point.

(second dividend) is dominant. So for the larger policy change, a tax on an inelastic good yields a larger efficiency gain (or smaller efficiency loss) from the environmental tax reform. Similarly, a tax switching to elastic demand incurs a larger efficiency loss (or smaller efficiency gain).

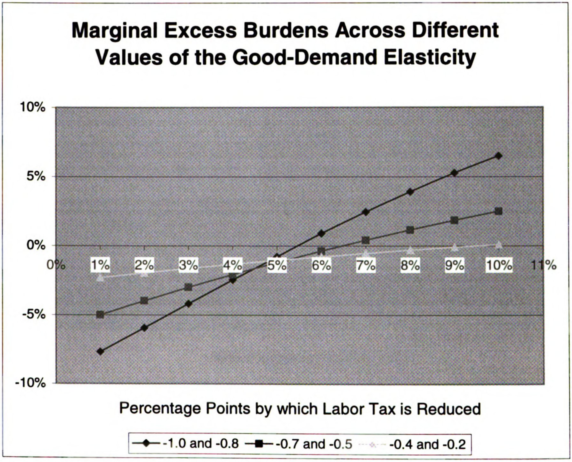

Figure III-15. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Good-Demand Elasticities (ε)

Again, the results of the sensitivity test show that the simulation result is mainly sensitive to the change of compensated elasticity (ε_c) than to the change of uncompensated elasticity (ε_u), since the type of policy change is differential analysis.

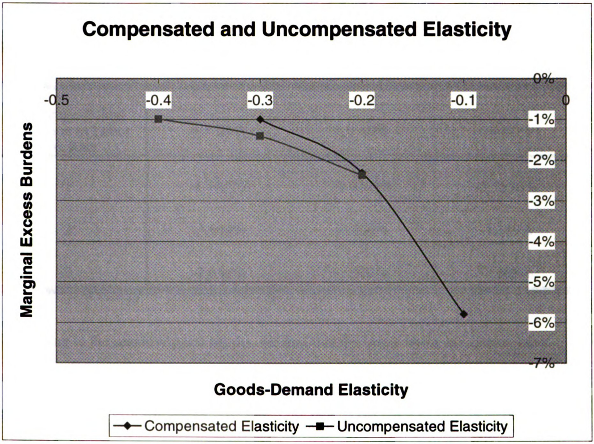

Figure III-16. Efficiency Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity of Goods-Demand Elasticity(ε)[33]

D-(3). Sensitivity Analysis with Respect to the Initial Tax Rates (t_L)

As before, the range of sensitivity analysis with respect to the initial labor tax rate is 20 percent to 60 percent. The other key parameters are set to their central values. The test results are summarized in Table III-10.

Table III-10 Marginal Excess Burden Across Different Initial Labor Tax Rates (t_L)

Percentage-Points-Reduction in Labor Tax Rate	t_L= 20%	t_L= 40%	t_L= 60%
1	-4.4667%	-4.9867%	-5.5556%
2	-3.549%	-3.974%	-4.389%
3	-2.654%	-3.007%	-3.308%

According to the sensitivity test results, we find that the larger initial tax rate on labor income (t_L= 60%) yields a larger efficiency gain, and the smaller initial tax rate (t_L=20%) generates smaller efficiency gain. The initial tax rate on the labor income determines the overall tax burden in the base case, because we assumed that the labor tax is the only distortionary tax in the base case. So if the labor-tax rate is high in the base case, the tax distortion of the base case is much more severe than in the case of a base case with a low tax rate. Thus for the same magnitude of the policy change, the base case with a higher tax

[33] For the test of compensated elasticity, the uncompensated elasticity is set to –0.4, and for the test of uncompensated elasticity the compensated elasticity is set to –0.1. The labor tax rate reduction is 1 percentage point.

rate yields a larger efficiency gain, because it has more room to improve for the new policy.

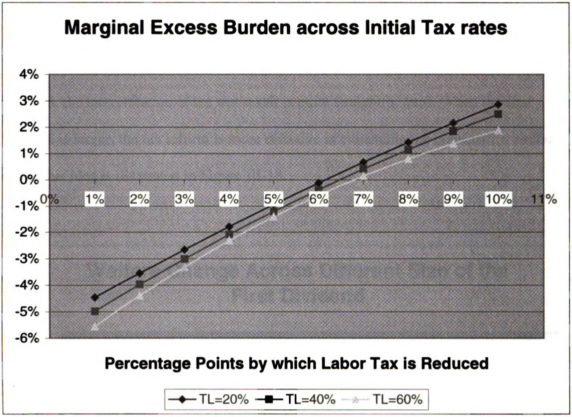

Figure III-17. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Initial Labor Tax Rates (t_L)

D-(4). Sensitivity analysis with Respect to the Environmental Damage

As before, the test range for the environmental damage is over the range of GDP loss of from 1 percent to 5 percent. The other key parameters are set to their central values during the sensitivity tests with respect to the environmental damage.

Since the level of the environmental damage determines the size of the first dividend, the interpretation of the test result is quite straightforward. When the first dividend is larger, the tax reform is more effective in enhancing the consumer's welfare level. This idea is illustrated in Figure III-18.

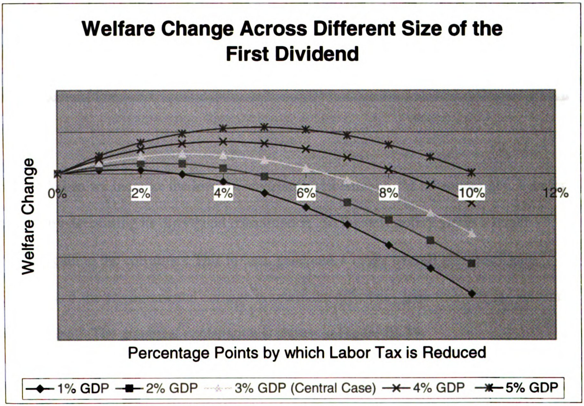

Figure III-18. Welfare Change across the Different Level of the First Dividend

Besides the welfare change, the change in the level of the first dividend can affect the marginal excess burden of the tax reform. The test results about marginal excess burden are summarized in Table III-11.

Table III-11 Marginal Excess Burden across different level of Environmental Damages

Percentage-Points-Reduction in Labor Tax Rate	1% GDP Loss	2% GDP Loss	3% GDP Loss	4% GDP Loss	5% GDP Loss
1	-1.693%	-3.342%	-4.9818%	-6.6249%	-8.2652%
2	-0.770%	-2.374%	-3.969%	-5.568%	-7.163%
3	0.108%	-1.451%	-3.002%	-3.591%	-6.108%

When we increase the level of environmental damage, the consumer gets a larger benefit by decreasing its dirty good consumption. So the new policy yields a larger welfare gain to the consumer. This in turn, generates a larger overall efficiency gain. Similarly, if the environmental damage is small, the efficiency gain from the tax reform will be small. The graphical explanation is shown in Figure III-19.

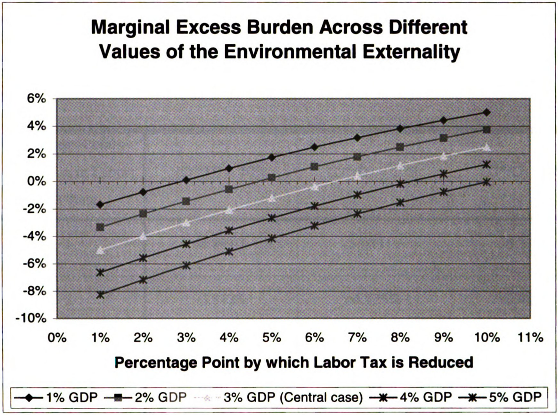

Figure III-19. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Environmental Damage (ΠD)

D-(5). Sensitivity Analysis with respect to the Ratio of (D*/D)

As before, the test range for the (D*/D) ratio is from 10% to 30%, and the other key parameters are set to their central values during the sensitivity test with respect to the (D*/D) ratio. A brief summary of the sensitivity test is available in Table III-12.

Table III-12. Marginal Excess Burden Across different (D*/D) Ratio

Percentage-Points-Reduction in Labor Tax Rate	(D*/D) = 10%	(D*/D) = 20%	(D*/D) = 30%
1	-4.881%	-5.0831%	-5.277%
2	-3.812%	-4.125%	-4.422%
3	-2.790%	-3.209%	-3.603%
...	...	...	...
10	3.014%	1.983%	1.051%

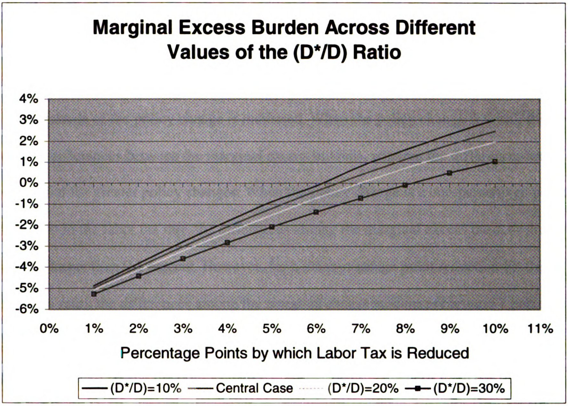

Figure III-20. Sensitivity of the Marginal Excess Burden of the Environmental Tax Change with respect to the Ratio of (D*/D)

From Table III-12 and Figure III-20, we see that a higher (D*/D) ratio will yield a larger welfare gain (or smaller welfare loss). Since the ratio of (D*/D) determines the degree of the non-homotheticity, the larger value of (D*/D) makes the new policy more effective.

One interesting fact that we get from this sensitivity test is the differences among the marginal excess burdens, for the various values of the (D*/D) ratio, are increased as the magnitude of the policy change is increased. When the policy change is small, there are tiny differences between the marginal excess burdens, whereas the differences are substantial for greater policy changes. When the policy change is a one-percentage-point reduction in the labor tax rate, the differences among the marginal excess burdens are slightly larger than 0.1 percent. However, for a ten-percentage-point reduction (in the labor tax rate), the differences among the marginal excess burdens are around 1 percent.

The reason for this divergence comes from the characteristics of the first and the second dividend. When the policy change is small, the direct benefit from the first dividend is dominant, and it increases at a nearly linear rate. So there is very little divergence among the marginal excess burdens. However, if the policy change is larger, the second dividend surpasses the first dividend. In addition, the negative second dividend increases at an increasing rate. Thus, when the policy change is large, the differences among the marginal excess burdens are increased.

The (D*/D) ratio is closely related to the second dividend, because it determines the degree of non-homotheticity. Thus the effect of a change in the (D*/D) ratio is magnified when the policy change is larger where the second dividend is dominant.

As before, we can also find the combinations of $|\varepsilon|$ and t_L that generate positive welfare gains. Figure III-21 shows the combinations of $|\varepsilon|$ and t_L that yield welfare gains from the tax reform. The vertical axis stands for the (uncompensated) good demand elasticity in absolute terms ($|\varepsilon_u|$), and the horizontal axis represents the magnitude of the policy change (Δt_L). The other key parameters are set to their central values except for the ε and t_L. The downward sloping line in Figure III-21 shows the combinations of policy parameters that are necessary to achieve a marginal excess burden of zero. Policy combinations that are up and to the right from the line represent positive marginal excess burden, *i.e.*, gross cost from the policy, whereas the below and to the left from the line means that the policy improves the tax efficiency.

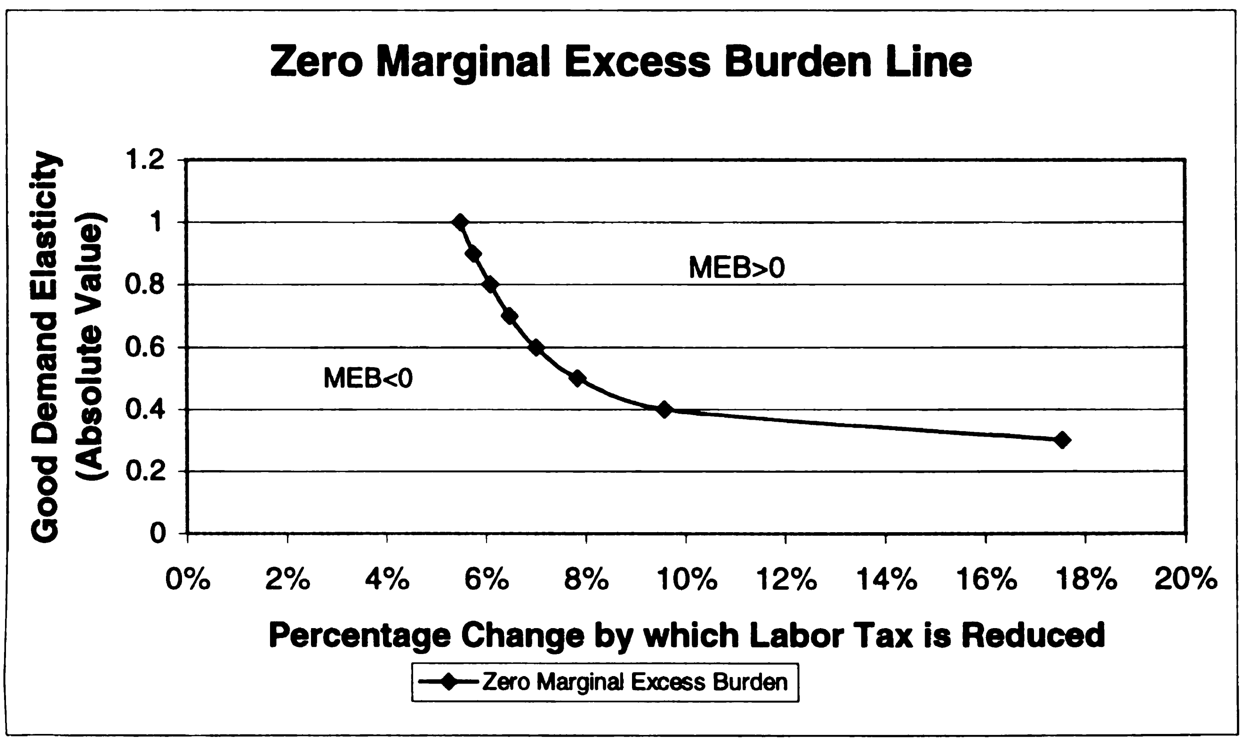

Figure III-21. The Combinations of ε and t_L that yields zero Marginal Excess Burden

From Figure III-21, we find that the new tax policy is much more effective when the goods demand elasticity is small. As we find in the sensitivity analysis, the smaller good demand elasticity enhances the effectiveness of the policy change.

The area under the line does not necessarily imply a double dividend, since the simulation result in this section reflects both the first dividend and the second dividend. Since in the non-homothetic utility function model, the ratio of (D*/D) determines the degree of non-homotheticity, it is interesting to investigate the effect of the (D*/D) ratio. Figure III-22 shows the way in which the zero-marginal excess burden line change when (D*/D) changes.

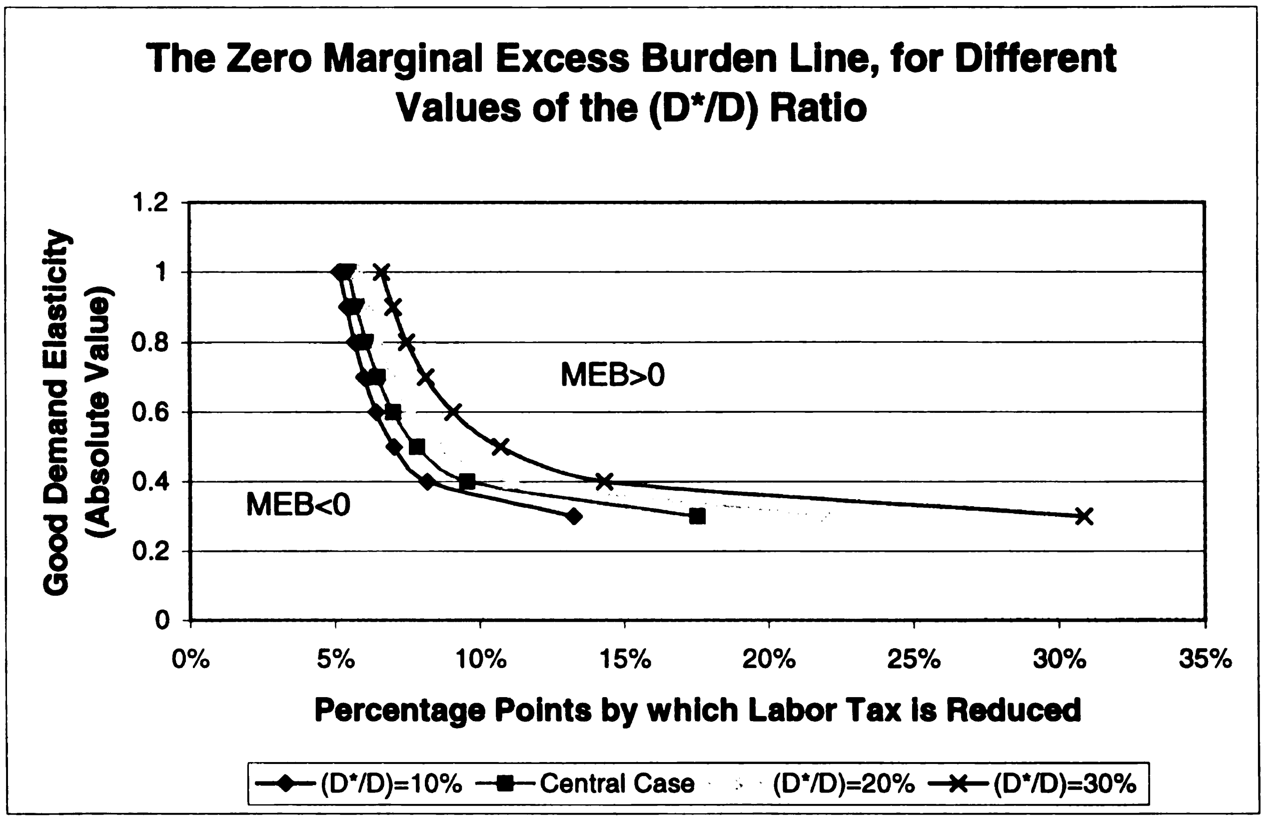

Figure III-22. The Combinations of |ε| and t_L that yield zero Marginal Excess Burden, for Different Values of the (D*/D) Ratio[34]

[34] The larger (D*/D) ratio enhances the effectiveness of the policy. Thus strong non-homotheticity extends the effective policy range.

E. Optimal Environmental Tax Rate

According to the simulations of the previous chapter, the optimal environmental tax rate was below the Pigouvian tax rate of the partial equilibrium. However, because all of the earlier theoretical and numerical results are based on the assumption of homothetic utility, we need to assess the generality of those arguments. So in this section, we will calculate the optimal environmental tax rate, using a model that relaxes the homotheticity assumption that earlier general-equilibrium studies have used.

In the central case of the simulation, four key elasticities are set to their routine central values. In the base case, a labor income tax of 40 percent is the only tax in this economy, and, in the revised case, the labor tax is replaced with the new environmental tax in a revenue-neutral manner. In the central case, the assumed marginal environmental damage is set to 0.03 in absolute value ($|\Pi|=0.03$), and later we will report on sensitivity analyses with respect to different values of the assumed marginal environmental damage (Π).

According to the central-case simulation results, under the non-homotheticity assumption, the optimal environmental tax rate lies *above* the Pigouvian tax. Since the assumed marginal environmental damage (Π) is 0.03 in absolute value, the optimal environmental tax rate in the partial equilibrium case, *i.e.*, the Pigouvian tax rate, should be 3% (0.03). In other words, in the first-best situation, the consumer's welfare gain would be maximized when the environmental tax rate reaches 3 percent. However, the simulation results for the second-best world show that the consumer's welfare gain is not maximized when the environmental tax rate is equal to the Pigouvian tax rate (3%).

Rather, the welfare gain is maximized when the environmental tax rate reaches 6.03%. From this result, we can conclude that the optimal environmental tax rate could be significantly higher than the Pigouvian tax rate, even when we allow the tax interaction between the pre-existing distortionary tax (labor income tax) and the newly introduced corrective tax (environmental tax) that occurs in the general-equilibrium situation. This is an entirely different result from the conclusion of the earlier general-equilibrium studies on this topic. The central case simulation results are illustrated in Figure III-23.

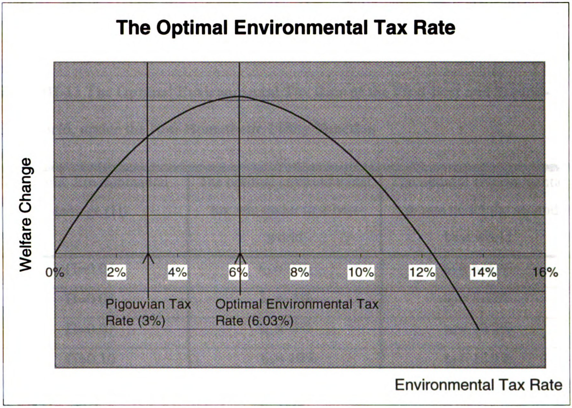

Figure III-23. The Optimal Environmental Tax Rate when the Marginal Environmental Damage is 3% (|Π|=0.03) and (D*/D)=15%

As we change the level of the assumed marginal environmental damage (Π), the optimal environmental tax rates are changed too, but the basic pattern is not changed: the optimal environmental tax rate lies *above* the Pigouvian tax rate under the non-homotheticity assumption. If we assume that the marginal environmental damage is 0.05 (in absolute terms), the consumer's welfare gain is maximized when the environmental tax rate is 8.1% rather than 5% (the partial-equilibrium Pigouvian tax). When we set the assumed marginal environmental damage to 0.07 in absolute terms, then the optimal environmental tax rate is 10.2%, which is larger than 7% of the Pigouvian tax rate. Table III-13 summarize the results.

Table III-13 The Optimal Environmental Tax Rate of the First-Best and Second-Best world, under the Non-Homothetic Utility Function

Marginal Environmental damage (Π)	The optimal environmental tax rate under first best world	The optimal environmental tax rate under the second best world
Π=0.03	t_D = 3%	t_D = 6.03%
Π=0.05	t_D = 5%	t_D = 8.12%
Π=0.07	t_D = 7%	t_D = 10.2%
Π=0.10	t_D = 10%	t_D = 13.1%

η_u=0.1, η_c=0.2, ε_u=-0.7, ε_c= -0.5, $\left(\frac{D*}{D}\right)$= 15%

Because the level of the (D*/D) ratio determines the degree of non-homotheticity, it is a good idea to see how the level of the (D*/D) ratio affects the optimal environmental tax rate. As we have seen earlier in the sensitivity analysis section of this chapter, the (D*/D) ratio will substantially affect the result of the environmental tax rate. The relationship between the level of (D*/D) and the optimal tax rate is summarized in Table III-14 below.

Table III-14 The Optimal Environmental Tax Rate across Different (D*/D) Ratio

		$\left(\frac{D*}{D}\right)=10\%$	$\left(\frac{D*}{D}\right)=20\%$	$\left(\frac{D*}{D}\right)=30\%$
Assumed Marginal Environmental Damage (Π)	Optimal environmental tax rate in the first best world	Optimal environmental tax rate in the second best world	Optimal environmental tax rate in the second best world	Optimal environmental tax rate in the second best world
0.03	3%	4.9%	7.7%	9.9%
0.05	5%	7.07%	9.7%	12.72%
0.07	7%	8.54%	11.07%	14.2%
0.10	10%	11.53%	14.54%	16.77%

From Table III-14, we find that as we increase the (D*/D) ratio, the optimal environmental tax rate is also increased. A larger (D*/D) ratio implies a stronger degree of non-homotheticity of the utility function. In turn, the stronger non-homotheticity increases the value of the optimal environmental tax rate.

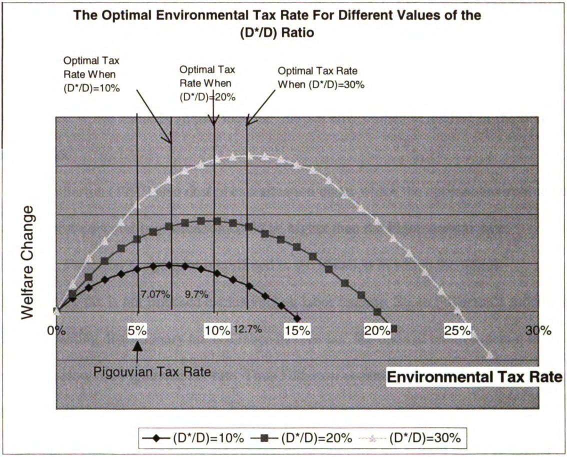

Figure III-24. The Optimal Environmental Tax Rate Across Different Valuee of (D*/D), when the Assumed Marginal Environmental Externality is 0.05 (|Π|=0.05)

So far, we have seen that the optimal environmental tax rate depends largely on the functional assumption. Earlier general-equilibrium studies about this topic indicate that the optimal environmental tax rate of the second-best world is smaller than that of the first-best situation (Pigouvian tax). In the previous chapter, when we performed simulations following the assumptions that Bovenberg and de Mooij made, we got results that support their arguments. However, in this chapter, the simulations relax the functional-form assumption, and we find that the optimal environmental tax rate of the second-best world could be higher than the optimal environmental tax rate of the first-best world.

Fullerton (1997) also describes a situation under which the optimal environmental tax rate of the second-best situation could be higher than the Pigouvian tax rate. However, Fullerton's argument is confined to the situation in which the initial distortionary tax is not imposed exclusively on labor income. So, in Fullerton's model, if the pre-existing distortionary tax is a labor-income tax, the optimal environmental tax rate lies below the Pigouvian tax rate. Thus Fullerton essentially confirms the previous argument of Bovenberg and his co-authors. Our findings overcome the limitations of Fullerton, because we show that the optimal environmental tax reform could be higher than the Pigouvian tax rate, even though the pre-existing distortionary tax is exclusively on labor income.

In summary, we find that the arguments of Bovenberg and his co-authors about the optimal environmental tax rate are correct only under a restricted set of functional-form assumptions. Thus, their conclusions should not be treated as general results about the optimal environmental tax rate of the second-best world.

III-4. More Analysis on the Non-Homotheticity

So far, our analysis of non-homotheticity is limited on positive minimum requirement of dirty good consumption (D*>0). However, needless to say, there are various ways to make the utility function non-homothetic. So, in this section, in order to have a better understanding about the relationship between 'double dividend' and 'non-homotheticity', I will broaden our analysis about non-homotheticity with various levels of minimum requirement of consumption on clean goods (C*), as well as dirty goods (D*).

A. Simulation Methods[35]

Because the main purpose of this simulation is to acquire a better understanding about relationship between 'double dividend' and 'non-homotheticity', our focus stays on the simulation results across various level of minimum requirement of consumptions (C*, D*). So, in this section, I will investigate the simulation results by changing the level of C* ((C*/C) ratio) and D* ((D*/D) ratio).

In order to keep the generality of the simulation results, the key parameters are set to their central values. That is, 0.1 for the uncompensated labor-supply elasticity (η_u), 0.2 the for compensated labor-supply elasticity (η_c), -0.7 for the uncompensated goods-demand elasticity (ε_u), -0.5 for the compensated goods-demand elasticity (ε_c), and the labor tax rate in the base case is 40 percent. Also, as before, in each revised case, the labor tax rate is reduced by 1 percentage point.

[35] The simulation model in this section does not include the environmental externality. So, the simulation results consider only the second dividend.

In the first set of simulations, I use a positive level of C* (and (C*/C) ratio) while keep the level of D* to zero. In the next set of simulations, I use various levels of C* (and (C*/C)) and D* (and (D*/D)), which are greater than zero. Since we already have simulation results about the case with positive D* and zero C* in the previous sections of this chapter, I will not report the results of this case. However, I will include the results for the final conclusion.

B. Simulation Results

Case 1: C*>0, and D*=0

Unlike the case of Chapter III-2, now the utility function is non-homothetic because of a positive level of mandatory consumption of clean good (C*), rather than D*. The simulation results are summarized in following table.

Table III-15. Simulation Results with Positive C* while D*=0

Percentage-Point-Reduction in the Labor Tax Rate	MEB when (C*/C)=10%	MEB when (C*/C)=20%	MEB when (C*/C)=30%
1	1.9206%	2.9975%	4.3736%
2	3.0401%	4.2486%	5.8067%
3	4.1014%	5.4285%	7.1534%

As seen in the table, the larger value of (C*/C) generates larger gross costs of the tax reform, since, as we increase the (C*/C) ratio, the values of marginal excess burden are increased. The reason for this result is that when we increase the level of the (C*/C) ratio, the consumer has to spend more on the clean good than when (C*/C) is 0%. This change implies a smaller tax base for the dirty good, and a higher environmental tax rate that is necessary for revenue neutrality. These changes lead to the severe tax-base erosion effect, so there is no double dividend. Thus, as we increase the level of the (C*/C) ratio, the marginal excess burden of the environmental tax reform becomes larger.

Note that the simulation results show that when (C*/C) is larger than (D*/D) which is set to zero, the environmental tax reform generates larger gross costs than when utility is homothetic ((D*/D)=(C*/C)=0%). This is because the tax-base erosion effect is more severe when (C*/C) ratio is greater than (D*/D), since a larger (C*/C) ratio reduces the tax base of environmental tax.

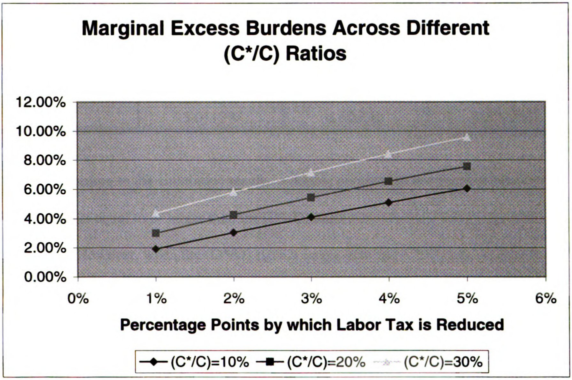

Figure III-25. Marginal Excess Burdens Across different Values of (C*/C) ratio, while (D*/D) is equal to zero.

Case 2. C*>0 and D*>0

In this section, I change the level of (C*/C) ratio, as well as (D*/D), in order to get more general results regarding the non-homotheticity. The combinations of (D*/D) and (C*/C) are:

φ (C*/C)=15% and (D*/D)=15%

κ (C*/C)=15% and (D*/D)=30%

λ (C*/C)=30% and (D*/D)=15%.

The simulation results are summarized in following table.

Table III-16. Simulation Results with Positive (C*/C) ratio and (D*/D) Ratio

Percentage-Point-Reduction in the Labor Tax Rate	MEB when (C*/C)=15%, (D*/D)=15%	MEB when (C*/C)=30%, (D*/D)=15%	MEB when (C*/C)=15%, (D*/D)=30%
1	1.0744%	2.4164%	**-0.2137%**
2	2.0719%	3.5487%	0.6145%
3	3.0112%	4.6043%	1.3934%

According to the simulation results, a double dividend is not possible when the (C*/C) ratio is equal to or larger than the (D*/D) ratio, since the new policy generates gross costs. However, when the (D*/D) ratio is larger than the (C*/C) ratio, a double dividend occurs for the smaller policy change. When the (D*/D) ratio is larger than the (C*/C) ratio (for the case of (C*/C)=15% and (D*/D)=30%), the environmental tax policy yields a negative marginal excess burden, which implies an efficiency gain in the tax system.

As mentioned before, when the (D*/D) ratio is relatively larger than the (C*/C) ratio, the tax base of the environmental tax becomes larger, which implies a smaller environmental tax rate that is necessary to keep the revenue neutrality. So the tax-interaction effect becomes weaker, so that the tax reform enhances overall tax efficiency. On the other hand, when the (C*/C) is larger than the (D*/D), the tax base for the environmental tax becomes smaller, which means a more severe tax-interaction effect.

By these simulation results, we reach a conclusion that even with the non-homotheticity assumption, an environmental tax policy could generates a double dividend only when the (D*/D) ratio is larger than the (C*/C) ratio. The graphical illustration is provided in following figure.

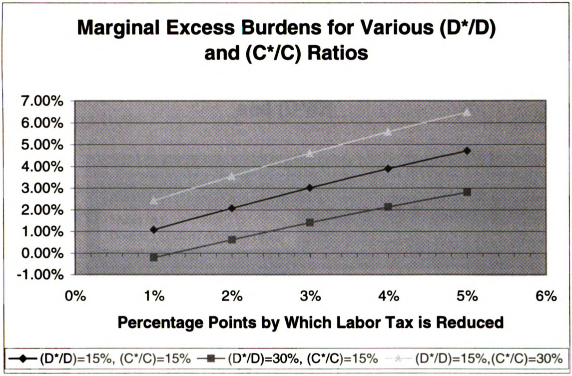

Figure III-26. Marginal Excess Burdens with Various Combinations of Positive (C*/C) ratio and (D*/D) Ratio

C. Conclusion

By the simulation results of this section, we could reach general conclusions regarding the non-homotheticity and double dividend issue. These are:

φ When (D*/D) > (C*/C), the second dividend could be positive. Thus, a double dividend of environmental tax policy is possible.

κ The magnitude of the second dividend becomes larger, as the relative size of (D*/D) is increased.

λ When (D*/D) ≤ (C*/C), the second dividend is negative. So there is no double dividend.

The conclusions are graphically illustrated by following figure.

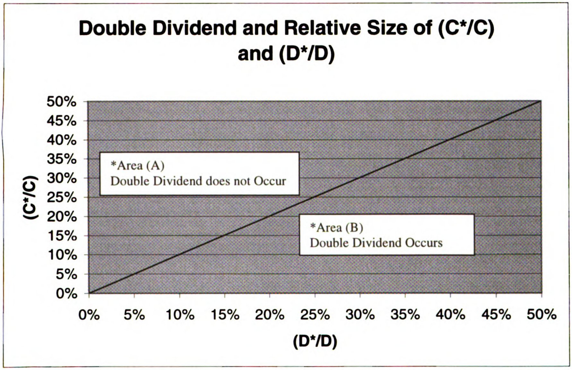

Figure III-27. The General Relationship Between Non-Homotheticity and Double Dividend

The line in the figure shows that the value of (C*/C) is equal to (D*/D). So the left- upper space (Area (A)) of the line stands for situations in which (C*/C) is larger than (D*/D), while the right-below space (Area (B)) of it represents situations in which (D*/D) is larger than (C*/C). According to the simulation results throughout this chapter, a double dividend is possible when the (D*/D) ratio is larger than the ratio of (C*/C). In this case (Area (B)), a tax on the dirty good is relatively more efficient, so the environmental tax policy could generates a double dividend. On the other hand, a double dividend does not occur when (C*/C) is larger than (D*/D) (Area (A)), because the tax on the dirty good is relatively less efficient.

Chapter IV

Double Dividend Analysis with Emission Tax Replacement

During the previous chapters, our analytical model has only considered taxes on the consumer goods whose use generates pollution. In this chapter, we will analyze the effects of a direct tax on emission itself, under the functional assumption of homothetic and non-homothetic utility.

It is generally accepted that a direct tax on emissions is more efficient than a tax on the consumption good which causes the pollution, because the effectiveness of the environmental tax is increased as we get close to the pollution[36]. In other words, relative to output taxes on goods whose use generates pollution, direct taxes on emissions can yield higher overall efficiency gains (or, generate less gross costs). However, according to Goulder (1995), even though a direct tax on the emission is more efficient than a tax on dirty good consumption, the results regarding the double dividend are not changed. He pointed out that, because of tax interactions between pre-existing distortionary taxes and the newly introduced environmental tax, environmental tax reform could not improve tax efficiency, even with direct emission taxation. However, Goulder does not provide any theoretical or numerical evidence to support this argument.

During the previous analysis, we learned that the earlier conclusion about the double dividend of an environmental tax is sensitive to the functional-form assumption. In this chapter, we will assess Goulder's assertion, regarding the double-dividend issue, by performing sets of simulations with and without the assumption of homotheticity.

[36] According to Oates (1995), the environmental tax should be designed to correspond as closely as possible to the pollution itself.

IV-1. Emission Tax Replacement with Homothetic Utility Function

Since the fundamentals of the simulation model in this chapter are basically the same as those of the one that we used in previous chapters[37], except the behavior of the producer, I will briefly describe the producer's problem.

A. Model[38]

In the base case, the producer's problem is the same as in previous chapters, since there is no tax on the producer side. In the revised case, however, a tax is levied on pollution. Therefore, the producer should change its behavior to adjust to the new situation. The firm's problem is to choose the amount of abatement that minimizes the total emission-related costs, which consist of emission tax and abatement costs. This can be written as

(IV-1) $\quad \text{Min} \quad t_E D(E + \Delta E) + \Psi(-\Delta E, D),$

where t_E is the emission tax, E is the per-unit emission of polluting output D, ΔE is the change in pollution per unit of output (thus $0 \leq \left|\frac{\Delta E}{E}\right| \leq 1$), and Ψ is the abatement-cost function. The firm's tax bill will decrease if it produces less output or undertakes explicit abatement.

The first-order condition of (IV-1) with respect to the level of abatement is

(IV-2) $\quad t_E D = \dfrac{d\Psi}{d\Delta E},$

[37] The utility function includes the environmental externality factor, as in Chapter II and Chapter III. For the explicit form of the utility function, please refer to equations (II-25), (III-32).

[38] The simulation model in this chapter closely follows the one by Ballard and Medema (1993).

which implies that the firm chooses the levels of abatement at which the marginal benefit from abatement ($t_E D$) is equal to the marginal cost.

The explicit form of the abatement cost function is

(IV-3) $\Psi = D\mu(-\Delta E)^{\theta}$,

where μ is the scale parameter of the abatement function and θ is its exponent. Note that, in this simulation, the abatement-cost function is assumed to be convex; thus, the value of θ is greater than 1.

B. Simulation Methods

As before, in the base case, the only distortionary tax in this economy is the labor income tax. In the revised case, the labor tax is replaced by an emission tax, rather than by the output tax on the dirty good consumption. Since the tax base of the emission tax is much narrower than that of the labor tax, the size of the policy change (the size of the labor tax reduction) is limited to be small, so that the emission tax can sustain the labor tax reduction[39].

In the central-case simulation, I employ the same values for the key parameters as before, such that we have 0.1 for uncompensated labor supply elasticity (η_u), 0.2 for compensated labor supply elasticity (η_c), -0.7 for uncompensated good demand elasticity (ε_u), and –0.5 for the compensated good demand elasticity (ε_c). Again, the labor tax rate in the base case is 40 percent. For the parameters of the abatement cost function, *i.e.* μ, θ, I follow the values that Ballard and Medema (1993) used, which are set to 0.0052 for μ and 1.25 for θ. For the size of the environmental externality, 3% of GDP loss is assumed.

[39] Note that, as before, the Labor income takes 100% of GDP, whereas the dirty good production accounts for 13% of GDP. It is assumed that the emission is less than 100% of the dirty-good production.

As briefly mentioned before, due to the mismatch of the size of tax bases, the policy changes should be small. Thus, in the each revised-case simulation, the labor taxes are reduced by 0.01 percentage point, and are replaced by emission taxes.

C. Simulation Results

The central-case simulation results are summarized in Table IV-1 below.

Table IV-1. Simulation Results of the Central Case (First and Second Dividend)

Labor Tax Rate in the Revised Case	Emission Tax Rate	Marginal Excess Burden
0.3999	0.0007487	-5.3658%
0.3998	0.0014979	-5.3485%
0.3997	0.0022476	-5.3340%

According to the simulation results, the emission tax replacement generates an efficiency gain, since the values of marginal excess burden are negative. However, it is very important not to misinterpret this result as meaning that a positive second dividend occurs by the emission tax replacement, because the simulation model analyzes both the first dividend and the second dividend. Thus we are not sure whether there is a positive second dividend unless we investigate the existence of second dividend.

According to the simulation results that consider the second dividend only, the emission tax policy generates gross costs (positive MEB), which implies there is no second dividend. Thus, under the homotheticity assumption, emission tax replacement could not yield double dividend.

Obviously, the simulation confirms Goulder's statement about the emission tax replacement, concerning the double-dividend issue. According to Goulder, as in the case of a tax on the dirty good, the newly introduced emission tax interacts with the pre-existing labor income tax, so it increases the overall tax distortion. Thus, by this mechanism, the emission-tax reform also degrades the efficiency of the tax system.

By the central-case simulation results, we reach a conclusion that under the assumptions of homothetic utility function, the emission tax replacement does generate a positive first dividend, but does not generate a second dividend. Thus, under the homotheticity assumption, a double dividend is not possible with the emission tax replacement. The simulation results are illustrated in Figure IV-1.

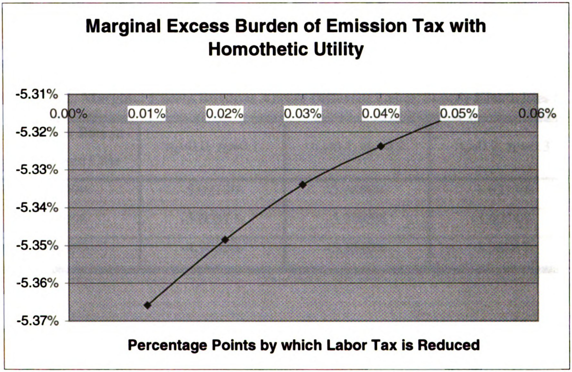

Figure IV-1. Marginal Excess Burden by the Emission Tax Replacement

D. Sensitivity Analysis

In this section, I will report the results of the sensitivity tests with respect to the labor-supply elasticity (η), the goods demand elasticity (ε), the initial labor tax rate (t_L).

D-(1). Sensitivity Analysis with respect to Labor-Supply Elasticity (η)

The labor-supply elasticity is related to the tax efficiency of the base case. When the value of labor-supply elasticity is large, the initial tax system is relatively more distorted. Thus, the new tax generates smaller gross costs of the tax reform when the labor-supply elasticity is larger. Similarly, the smaller labor-supply elasticity implies better tax efficiency in the base case, so the new tax policy generates larger gross costs. These results are summarized in Table IV-2, and Figure IV-2.

Table IV-2. Marginal Excess Burdens Across Different Labor Supply Elasticities (η)

Labor Tax Rate in the Revised Case	η_u=0.0, η_c=0.1	η_u=0.1, η_c=0.2	η_u=0.2, η_c=0.3
0.3999	-5.0213%	-5.3658%	-5.6213%
0.3998	-5.0037%	-5.3485%	-5.6034%
0.3997	-4.9883%	-5.3340%	-5.5884%

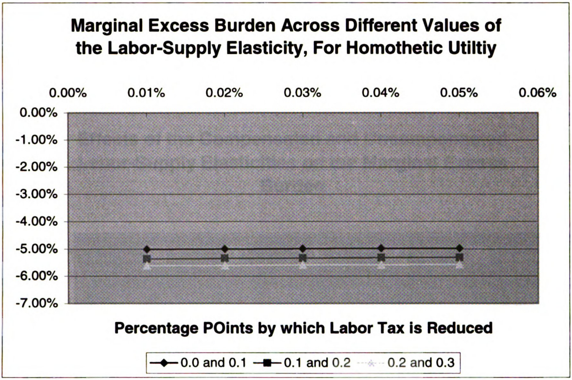

Figure IV-2. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Labor-Supply Elasticities (η)

Note that, according to the simulation results, the simulation model is not very sensitive to the labor-supply elasticity (η), since the differences of the marginal excess burden from the different values are relatively small.

As with the results of previous chapters, the sensitivity tests results show that the simulation results are more sensitive to the compensated elasticity than to the uncompensated elasticity, because, in a differential analysis, the compensated elasticity is more important. This result is illustrated in Figure IV-3.

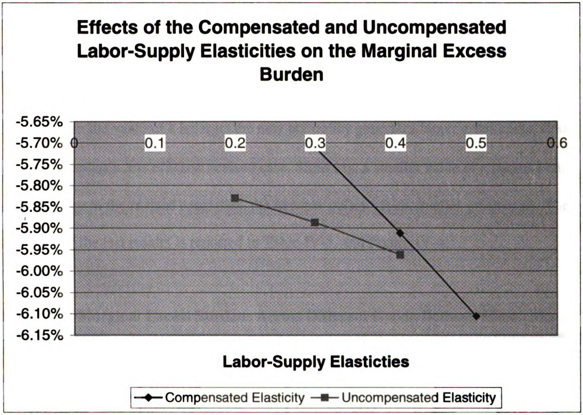

Figure IV-3. Efficiency Cost (Marginal Excess Burden) of the Emission-Tax Experiment, Comparison Between Compensated Elasticity and Uncompensated Elasticity of Labor-Supply Elasticity (η)[40]

[40] For the test of compensated elasticity the uncompensated elasticity is set to 0.2, and for the test of uncompensated elasticity the compensated elasticity is set to 0.5. The labor tax reduction is 0.1 percentage point reduction in labor-tax rate

D-(2) Sensitivity Analysis with respect to the Goods-Demand Elasticity (ε)

In this subsection, I will report the sensitivity test results with respect to the goods-demand elasticity (ε). The level of goods-demand elasticity is related to the tax efficiency of the revised case, even though the tax is not directly imposed on the dirty good consumption, because the supply curve of the dirty good is perfectly horizontal in this model. So in this case, the producer can transfer all of its tax burden to the consumer. Thus, although the tax is not a consumer-side one, the elasticity of the consumer's demand is an important major factor in analyzing the tax efficiency.

When the value of ε is large, the new tax policy generates larger gross costs, since a larger ε implies a less efficient revised case. Similarly, a smaller value of ε means better tax efficiency in the revised case; thus, the new tax policy yields smaller gross costs. The summary of the test results is reported in Table IV-3, and Figure IV-4.

Table IV-3 Marginal Excess Burdens Across Different Goods-Demand Elasticities (ε)

Labor Tax Rate in the Revised Case	ε_u=-1.0, ε_c=-0.8	ε_u=-0.7, ε_c=-0.5	ε_u=-0.4, ε_c=-0.2
0.3999	-2.0237%	-5.3658%	-9.7378%
0.3998	-2.0183%	-5.3485%	-9.7093%
0.3997	-2.0159%	-5.3340%	-9.6836%

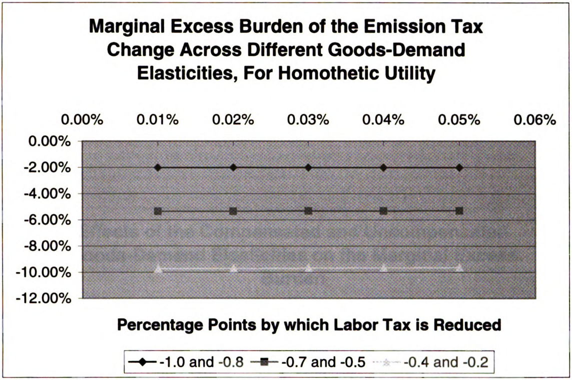

Figure IV-4. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Goods-Demand Elasticities (ε)

According to the tests, the simulation results are very sensitive to the change of goods-demand elasticity (ε). One of the reason for this sensitiveness is that this simulation model considers both the first and second dividend. Since in this model, the first dividend is mainly related with the consumption of the dirty good, the change of goods-demand elasticity and the dirty good consumption magnify the size of the first dividend.

Also, the simulation results are more sensitive to the compensated elasticity (ε_c) than to the uncompensated elasticity (ε_u), since, in the differential analysis, the compensated elasticity is more important. Theses results are illustrated by Figure IV-5.

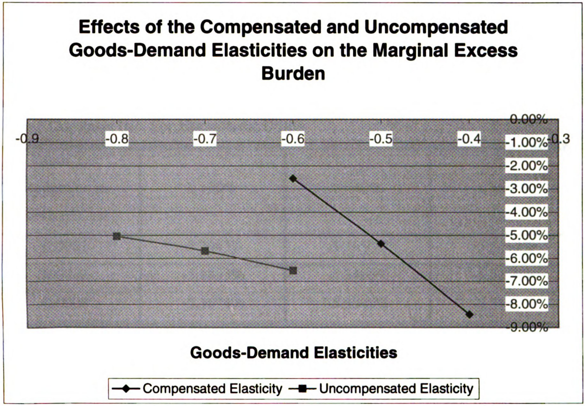

Figure IV-5. Efficiency Cost (Marginal Excess Burden) Comparison Between Compensated Elasticity and Uncompensated Elasticity of Goods-Demand Elasticity (ε)[41]

D-(3). Sensitivity Analysis with respect to the Initial Tax Rates (t_L)

The initial labor tax rate is also related to the tax efficiency of the base case. When the initial labor tax rate is high, the base case tax system is more distorted than when the labor tax rate is low. Thus, the new tax policy with a reduced labor tax rate generates a relatively smaller marginal excess burden when the initial tax rate is high. Similarly, the new tax policy yields larger marginal excess burden when the initial labor tax rate is low, since in this case, the base case is relatively less distorted.

Table IV-4. Marginal Excess Burdens of the Emission Tax Change Across Different Initial Tax Rates (t_L), For Homothetic Utility

Labor Tax Reduction in Revised Case	t_L=30%	t_L=40%	t_L=50%
0.0001	-5.2043%	-5.3658%	-5.5412%
0.0002	-5.1833%	-5.3485%	-5.5260%
0.0003	-5.1674%	-5.3340%	-5.5128%

[41] For the test of compensated elasticity, the uncompensated elasticity is set to -0.7, and for the test of uncompensated elasticity the compensated elasticity is set to -0.5. The labor tax is reduced by 0.1

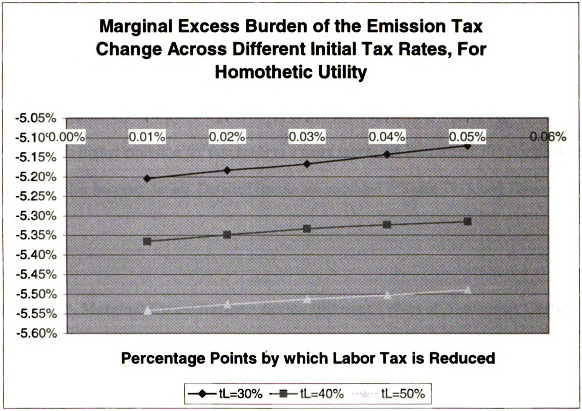

Figure IV-6. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Initial Tax Rates (t_L)

percentage point.

D-(4). Sensitivity Analysis with respect to the Exponent of Abatement Cost Function (θ)

Here, I report the sensitivity test results with respect to the exponent of abatement cost function (θ)[42]. I set the test range for θ from 1.05 to 1.45. Again, in order to keep the convexity of the abatement costs function, the value of θ should be larger than 1.0.

The value of θ determines the shape of the abatement cost function. When the value of θ is high, the marginal abatement cost is high. When θ is high, the emission tax rate that is necessary to achieve a given level of pollution abatement will be higher. Because the higher emission tax rate leads to a more severe tax interaction, the marginal excess burden becomes larger. Detailed results are provided in Table IV-5, and Figure IV-7.

Table IV-5. Marginal Excess Burdens Across Different Values of Abatement Costs (θ)

Labor Tax Rates in the Revised Case	θ=1.05	θ=1.15	θ=1.35	θ=1.45
0.3999	-5.3658%	-5.3658%	-5.3640%	-5.3621%
0.3998	-5.3486%	-5.3485%	-5.3465%	-5.3435%
0.3997	-5.3342%	-5.3341%	-5.3315%	-5.3280%

[42] Since the simulation results are not very sensitive to the scale parameter in the abatement cost function (μ), our discussion is limited to the exponent parameter (θ) only.

Note that the test results of θ=1.05 and θ=1.15 are very similar, whereas the results of θ=1.35 and θ=1.45 are relatively different. The reason for this result is that each of theses cases in a given row of the table involves approximately the same amount of emission tax revenue, because each involves the same labor tax rate. But they must have different amounts of pollution abatement, since θ is an exponent.

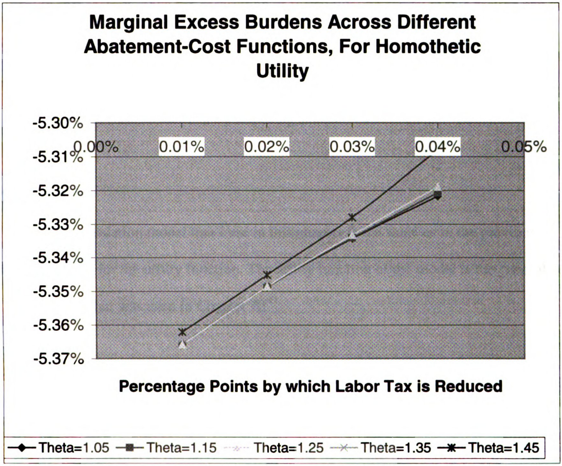

Figure IV-7. sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Exponent in the Abatement-Cost Function.

IV-2. Emission Tax Replacement with Non-Homothetic Utility Function

The purpose of the simulation in this chapter is to check the generality of the previous argument about emission tax replacement and the double dividend. In order to check the generality, I change the homotheticity assumption for the consumer's preference. So, as before, I will use a non-homothetic utility function for the simulation model in this section. Thus the description of the simulation model in this section can be summarized as:

- Non-Homothetic Utility Function
- Producer Side Abatement by Imposing Emission Tax

A. Model

The simulation model that I use in this chapter is the same as in the previous section, except for the utility function. The utility function of the model is the generalized CES function that was used in Chapter III[43].

B. Simulation Method

As before, in the base case, there is a 40-percent labor tax in this economy. In the revised case, a portion of the labor tax is replaced by an emission tax (rather than the output tax on dirty good consumption). Due to the size difference between the tax base of the labor tax and the emission tax, the policy change (labor tax reduction) should be

[43] As in Chapter IV-1, the utility function includes the environmental externality to analyze both the first and second dividend. For the explicit form of utility function, please refer to equations (II-25), (III-32).

small. Thus, in each revised-case simulation, the labor taxes are reduced by 0.01 percentage point, and are replaced by emission taxes.

In the central-case simulation, I employ the same values for the key elasticity parameters as before. For the parameters for the abatement cost function, *i.e.*, μ, θ, I follow the values that Ballard and Medema (1993) used, such that μ=0.0052 and θ=1.25. The level of (D*/D) ratio is set to 15% for most simulations in this section. Also, it is assumed 3 percent of GDP loss as environmental externality.

C. Simulation Results

According to the simulation results that consider the second dividend only, the emission tax replacement generates negative marginal excess burden, which implies a positive second dividend. That means the new policy generates a double dividend, under the assumption of non-homothetic utility. In addition, the (positive) first dividend significantly improves the overall tax efficiency. Table IV-5 summarizes the results of the central case simulation, which considers both first and second dividend.

Table IV-6. Simulation Results of the Central Case (First and Second Dividend)

Labor Tax Rate in the Revised Case	Emission Tax Rate	Marginal Excess Burden
0.3999	0.0006540	-7.4935%
0.3998	0.0013083	-7.4778%
0.3997	0.0019631	-7.4640%

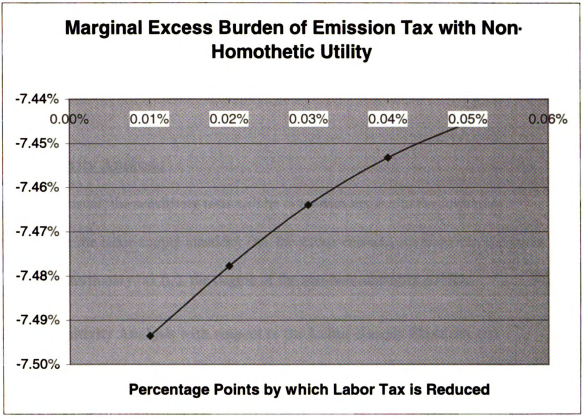

Figure IV-8. Simulation Results of the Central Case

The simulation results show that the double dividend is possible with the emission tax replacement, if we employ a non-homothetic utility function. This is the opposite result to the idea of Goulder. According to Goulder, even though the regulator uses an emission tax, which is being considered as a more efficient tax than a consumer-side commodity tax, it could not improve the tax efficiency of the overall tax system because of the tax-interaction effect. However, as in Chapter III, under the assumption of non-homotheticity, the tax-interaction effect becomes weaker. Thus, it is outweighed by the positive effect of the tax reform (revenue-recycling effect). The general result is that the emission-tax reform yields a positive second dividend, so the double dividend is possible.

Therefore, the idea of Goulder about the emission tax replacement (instead of output tax on the dirty good consumption) is not a generally applicable conclusion about the double dividend.

D. Sensitivity Analysis

As usual, the sensitivity tests will be done with respect to the important parameters: the labor-supply elasticity (η), the goods-demand elasticity (ε), the initial level of distortionary tax (t_L), the degree of the non-homotheticity (D^*/D).

D-(1). Sensitivity Analysis with respect to the Labor-Supply Elasticity (η)

The labor-supply elasticity is related to the tax efficiency of the base case. Thus, when the value of labor-supply elasticity is large, the base case is less efficient. Therefore, the new policy generates a larger efficiency gain when the labor-supply elasticity is larger. On the other hand, when the labor-supply elasticity is small, the new policy yields a smaller efficiency gain, since the base case is relatively efficient. Detailed test results are provided in Table IV-6 and Figure IV-8.

Table IV-7. Marginal Excess Burdens Across Different Labor-Supply Elasticities (η)

Labor Tax Rate in the Revised Case	η_u=0.0, η_c=0.1	η_u=0.1, η_c=0.2	η_u=0.2, η_c=0.3
0.3999	-6.8538%	-7.4935%	-8.2420%
0.3998	-6.8383%	-7.4778%	-8.2260%
0.3997	-6.8248%	-7.4640%	-8.2121%

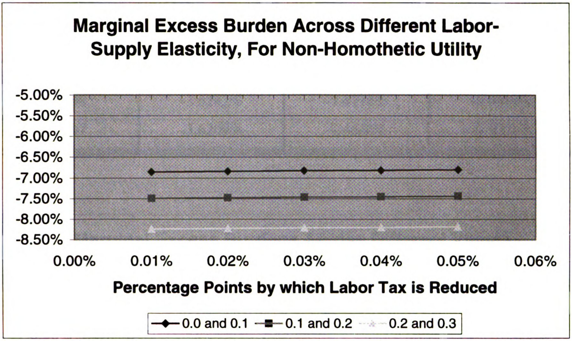

Figure IV-9. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Labor-Supply Elasticities (η), For (D*/D)=15%

D-(2). Sensitivity Analysis with Respect to the Goods-Demand Elasticity (ε)

As mentioned before, although the emission tax is not a direct tax on the consumer, under the perfectly horizontal supply curve of the dirty good, the elasticity of goods demand (ε) is also important in analyzing tax efficiency. We have similar test results to the case of the consumer side tax (tax on dirty good consumption) regarding the goods-demand elasticity (ε). That is, when the goods-demand elasticity is smaller, the new tax policy yields a larger gain in tax efficiency, since the revised case is relatively efficient. Likewise, a larger value of the goods-demand elasticity generates a smaller efficiency gain, because the revised case is relatively less efficient. Detailed test results are provided in Table IV-7 and Figure IV-9.

Table IV-8. Marginal Excess Burdens Across Different Goods-Demand Elasticities (ε)

Labor Tax Rate in the Revised Case	ε_u=-1.0 and ε_c=-0.8	ε_u=-0.7 and ε_c=-0.5	ε_u=-0.4 and ε_c=-0.2
0.3999	-3.6295%	-7.4935%	-9.9821%
0.3998	-3.6242%	-7.4778%	-9.9589%
0.3997	-3.6209%	-7.4640%	-9.9376%

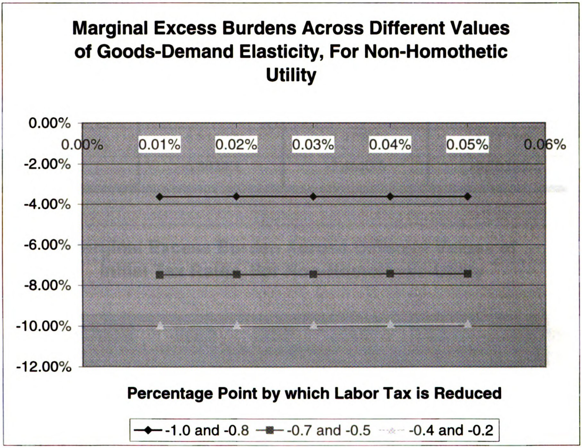

Figure IV-10. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Goods-Demand Elasticities (ε), for (D*/D)=15%

D-(3). Sensitivity Analysis with respect to Initial Labor-Tax Rates (t_L)

We have similar results to previous simulations regarding the initial distortionary tax rate (t_L). If the initial tax system is highly distorted (higher t_L in the base case), then the new tax policy generates a larger efficiency gain. Similarly, when the initial tax rate is low, *i.e.*, less distorted, the new tax policy makes a smaller gain in tax efficiency. The results of this analysis are summarized in Table IV-8, and Figure IV-10.

Table IV-9. Marginal Excess Burdens Across Different Initial Tax Rates (t_L)

Labor Tax Rate in the Revised Case	t_L=30%	t_L=40%	t_L=50%
0.3999	-6.8284%	-7.4935%	-8.7355%
0.3998	-6.8149%	-7.4778%	-8.7173%
0.3997	-6.8024%	-7.4640%	-8.7021%

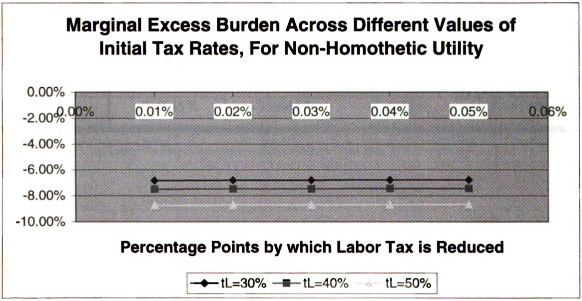

Figure IV-11. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Initial Tax Rates (t_L)

D-(4). Sensitivity Analysis with Respect to the Exponent of Abatement-Cost Function

The results of sensitivity test with respect to exponent in the abatement function (θ) are summarized in Table IV-10. According to the test results, a larger value of θ generates a smaller efficiency gain, since the marginal abatement costs goes up when θ is increased. Holding constant the level of abatement, higher marginal abatement costs generally make it necessary to have a higher emission tax rate, to maintain the revenue neutrality. Because a higher emission tax rate increases the tax-interaction effect, the efficiency gain is decreased.

Table IV-10. Marginal Excess Burdens Across Different Values of Abatement Cost (θ)

Labor Tax Rates in the Revised Case	θ=1.05	θ=1.15	θ=1.35	θ=1.45
0.3999	-7.4935%	-7.4935%	-7.4930%	-7.4920%
0.3998	-7.4778%	-7.4778%	-7.4771%	-7.4758%
0.3997	-7.4645%	-7.4643%	-7.4631%	-7.4614%

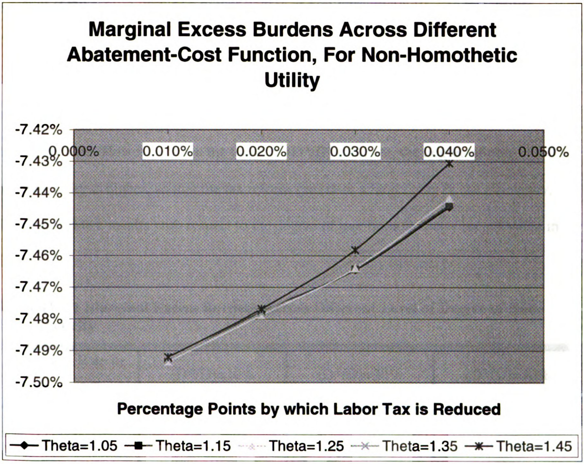

Figure IV-12. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Exponent in the Abatement-Cost Function

D-(5). Sensitivity Analysis with respect to the Degree of Non-Homotheticity ((D*/D)

The value of the (D*/D) ratio determines the degree of the non-homotheticity, *i.e.*, a higher (D*/D) ratio implies a higher degree of non-homotheticity. The test results indicate that the simulation results are very sensitive to the change of the degree of non-homotheticity. When the value of (D*/D) ratio is smaller, the consumer's preference has weaker non-homotheticity, and the emission tax reform generates a relatively smaller efficiency gain. However, when the value of (D*/D) is higher, the degree of non-homotheticity is higher, so that the tax reform generates a larger gain in tax efficiency. The detailed test results with respect to the degree of non-homotheticity are provided in Table IV-10.

Table IV-11 Marginal Excess Burdens Across Different Level of Degree of Non-Homotheticity

Labor Tax Rate in the Revised Case	(D*/D)=10%	(D*/D)=20%	(D*/D)=30%
0.3999	-6.4576%	-8.6052%	-10.7528%
0.3998	-6.4411%	-8.5916%	-10.7399%
0.3997	-6.4268%	-8.5790%	-10.7302%

Throughout the sensitivity analysis in this chapter, we find that the simulation results are mainly sensitive to the change of the degree of non-homotheticity (D*/D). Even though the simulation results are somewhat sensitive to the other parameters, the results are much more sensitive to the change of (D*/D) ratio. From this finding, we get an important implication regarding the issue of double dividend: the non-homotheticity is the one of the major factor to upset the previous conclusion about this issue.

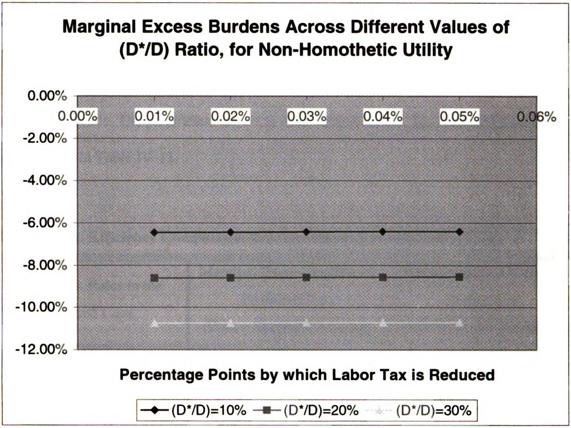

Figure IV-13. Sensitivity of the Marginal Excess Burden of the Emission Tax Change with respect to the Degree of Non-Homotheticity ((D*/D))

E. Comparison Between Output Tax and Emission Tax

In this subsection, I will compare the simulation results between an indirect environmental tax, such as a consumption tax on the dirty good, and a direct environmental tax, *i.e.*, a tax on emission, under the non-homotheticity assumption. In order to preserve the generality of the results, I use the same parameters and size of the policy change for both simulations. Note that the simulations analyze both the first and second dividends. The parameters are set to their central values. The simulation results are reported in Table IV-12.

Table IV-12. Efficiency Comparison Between Direct Tax and Indirect Tax

Labor Tax Rates in the Revised Case	Marginal Excess Burden of Emission Tax (First + Second Dividend)	Marginal Excess Burden of Output Tax (First + Second Dividend)
0.3999	-7.4935%	-7.4823
0.3998	-7.4778%	-7.4665
0.3997	-7.4640%	-7.4525

According to the simulation results, under the non-homotheticity assumption, both the direct emission tax and the indirect tax on the polluting good (output tax) generate negative marginal excess burden. Along with the simulation result that considers

the second dividend[44] only, we reach a conclusion that both policies yield double dividends. The major reason for this result is that the tax-interaction effect is much weaker under the non-homotheticity assumption. As I explained in Chapter III, the existence of a minimum requirement of consumption (D*) mitigates the tax-base erosion effect, so that the new tax policy enhances overall tax efficiency. The importance of this finding is that the double dividend is possible for both kinds of tax reform, if we assume a non-homothetic utility function.

The size of the efficiency gain is slightly larger in the case of the direct tax on emissions, since the effectiveness of tax reform is increased, as the method of taxation gets closer to the pollution. This result confirms the previous environmental tax theory.

The simulation result that considers second dividend shows that both policies generate negative marginal excess burden. Thus, both policies generate double dividend when non-homotheticity is assumed.

Chapter V

Discussions and Conclusions

In this chapter, I will summarize the results that we find in Chapters II, III, and IV, and discuss several important matters regarding the topics of this research. During the couple of previous chapters, I perform the simulations to verify whether the results of earlier general-equilibrium studies are generally acceptable. We find that the double-dividend hypothesis is rejected under the assumption of homothetic utility function, but the double dividend of an environmental tax reform is possible if we use a model that has a non-homothetic utility function. In addition, I find that the argument of previous general-equilibrium studies about the optimal environmental tax rate under the second-best world is only correct under the special functional assumption, so the optimal environmental tax rate could lie above the Pigouvian Tax rate. In the next sections, we review and summarize the key findings of this study.

V-1. Double Dividend of Environmental Tax Reform is Possible.

Bovenberg and his co-authors criticize the double-dividend hypothesis of partial-equilibrium studies, because the partial-equilibrium studies neglect the tax interactions that occur in the general equilibrium. A newly introduced environmental tax will interact with the pre-existing distortionary taxes, so that the environmental tax reform will exacerbate the tax distortion of the tax system rather than mitigate it, in the multi-market general-equilibrium situation. These authors demonstrate their ideas about this topic analytically or numerically, and provide the conclusion that a double dividend is possible only under unrealistic circumstances.

The simulations in Chapter II confirm the argument of Bovenberg and his co-authors, because the simulation results show that the double dividend is not possible under the assumptions of Bovenberg and de Mooij. However, we find the conditions under which Bovenberg and de Mooij (1994) derive their conclusion, *i.e.*, homothetic utility function and the labor income tax is the only tax in the initial situation, are very similar to the conditions, under which the famous Ramsey rule implies that uniform taxes are uniform. This raises a doubt about the generality of the conclusion of Bovenberg and his co-authors, and motivates me to verify the generality of their conclusion.

As we show in Chapter III and IV, a double dividend of environmental tax reform is possible, if we relax the assumption of homotheticity of the utility function. Moreover, the likelihood of a double dividend increases as the degree of non-homotheticity of the utility function increases. By our simulations with non-homotheticity, we conclude that the results regarding the double dividend are sensitive to the functional-form assumption, so the conclusion of Bovenberg and his co-authors about this topic should not be treated as a general result.

The side-by-side comparison about the results of environmental tax reform is briefly reported in the following figures. Figure V-1 shows the profiles of the consumer's welfare change induced by the environmental tax reform, between homothetic and non-homothetic utility function. Note that it shows the pure second dividend, abstracting from the first dividend.

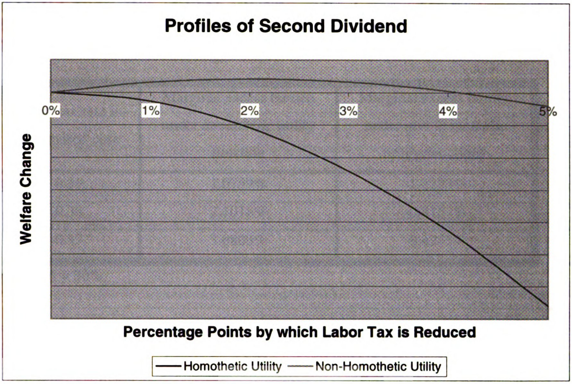

Figure V-1. The Comparison of Welfare Change between Homothetic utility function and Non-homothetic utility function

Table V-1 and Figure V-2 show the comparison of efficiency costs of the environmental tax reform between homothetic and non-homothetic utility function. The labor tax rate in the base case is 40 percent, and both consider the second dividend only.

Table V-1. Comparison of the Marginal Excess Burden caused by Environmental Tax (tax on the consumption of polluting goods) Reform between Homothetic and Non-Homothetic Utility Function

Labor tax rate in the revised case	Marginal excess burden under *homothetic* utility function	Marginal excess burden under *non-homothetic* utility function*
0.39	1.0739%	-1.2223%
0.38	2.1018%	-0.8157%
0.37	3.0803%	-0.4235%

* (D*/D) = 30%

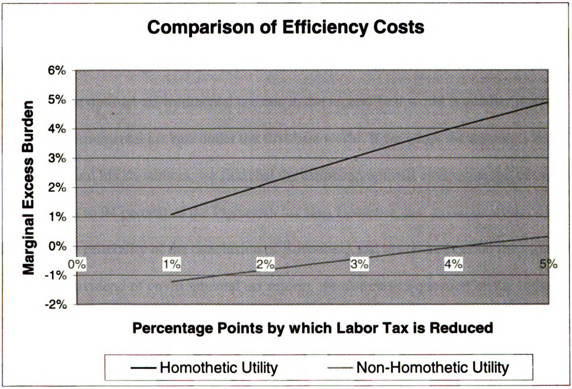

Figure V-2. Comparison of Marginal Excess Burden between Homothetic and Non-Homothetic Utility Function (Tax on the Consumption of Polluting Goods)

V-2. The Optimal Environmental Tax Rate Could Lie Above the Pigouvian Tax Rate

Bovenberg and de Mooij (1994) point out that the optimal environmental tax rate in the general-equilibrium second-best situation typically lies below the Pigouvian tax rate of partial-equilibrium analysis, due to the tax-interaction effect. Several other studies support this idea of Bovenberg and de Mooij, both numerically and analytically, and they suggest that the optimal environmental tax rate in the second-best world is around 70 percent to 90 percent of the Pigouvian tax rate.

During the simulations in Chapter II, I confirm the idea of the previous general-equilibrium studies, regarding the optimal environmental tax rate. Our simulation results show that the optimal environmental tax rate in the second-best world is smaller than the optimal environmental tax rate under the first-best world. If we adopt the assumptions of Bovenberg and his co-authors, we find that the estimated optimal environmental tax rate is 89 percent to 94 percent of the Pigouvian tax rate. However, just as our analysis casts doubt on the generality of the conclusion of Bovenberg and his co-authors on the topic of the double dividend of environmental tax reform, we also raise a question on the topic of the environmental tax rate in the second-best world. To verify the generality, we relax the assumption of homotheticity of the utility function in the simulation model, as we did in the previous simulations for the double-dividend hypothesis.

In Chapter III, I relax the homotheticity assumption by employing a non-homothetic utility function. The simulation result of Chapter III shows that the optimal environmental tax rate is actually higher than the Pigouvian tax rate. This result clearly upsets the conclusion of earlier general-equilibrium studies. Thus we conclude that the argument of previous general-equilibrium studies is only correct under the assumptions they made, and there is no presumption about optimal environmental tax rate in the second-best world.

A brief comparison of the optimal environmental tax rate between the first-best situation and the second-best situation, and a comparison between the homothetic utility function and non-homothetic utility function, is provided in the following table.

Table V-2. Comparison of Optimal Environmental Tax Rate under the First-Best and Second-Best World and Homothetic and Non-Homothetic Utility Function

Assumed Marginal Environmental Damages (in absolute terms)	The Optimal Environmental Tax rate under the First-best world (Pigouvian Tax)	The Optimal Environmental Tax Rate under the Second-best world	
		Homothetic Utility Function	Non- Homothetic Utility Function*
Π=0.03	t_D = 3%	t_D = 2.74%	t_D = 6.03%
Π=0.05	t_D = 5%	t_D = 4.60%	t_D = 8.12%
Π=0.07	t_D = 7%	t_D = 6.18%	t_D = 10.2%
Π=0.10	t_D = 10%	t_D = 9.40%	t_D = 13.1%

$\varepsilon_u = -0.7$, $\varepsilon_c = -0.5$, $\eta_u=0.1$ and $\eta_c=0.2$

$* \left(\frac{D*}{D}\right) = 15\%$

V-3. Role of Minimum Requirement of Consumption (D*)

In this section, we will discuss the role of the minimum requirement of consumptions (C* and D*) in the simulation model in Chapter III and Chapter IV, which are critical for creating the non-homothetic utility function. Since we assume the minimum requirement of clean good consumption is zero, *i.e.* C*=0, for analytical convenience during the simulations, our discussion on the minimum requirement of consumption will be limited on D*.

As mentioned before, the critical reason that Bovenberg and his co-authors reach the same conclusion that rejects the double-dividend hypothesis is that they all use the same functional assumption on the consumer's preferences, the homothetic and separable utility function. To prove this idea, we need to employ a utility a utility function that is not homothetic (between clean and dirty good). Thus we use a generalized CES utility function, which is non-homothetic. Because of the non-zero and positive level of mandatory dirty-good consumption (D*) in the inner nest of the consumer's utility function, the consumer's preferences become non-homothetic. So, in this sense, we might declare that the first role of the minimum requirement consumption of the dirty good (D*) is making the utility function non-homothetic. Note that, with the positive amount of D*, the utility function is not homothetic with respect to the origin but homothetic with respect to the displaced origin (C*, D*).

What are the practical roles of the mandatory spending on the dirty good consumption (D*) in our simulations? As we find in Chapter III, the level of D* controls the degree of the non-homotheticity of utility function. During the sensitivity analysis for the level of D*, in the form of (D*/D) ratio, we perform the sensitivity tests of the mandatory spending on the dirty good. As the level of the (D*/D) ratio is increased, the utility function has a stronger degree of non-homotheticity, so that the larger (D*/D) ratio yields larger welfare gains and smaller efficiency costs from the environmental tax reform. Thus, the level of D*, in the form of (D*/D) in our simulation model, determines the degree of non-homotheticity of the utility function, which in turn, controls the simulation results.

Besides the roles of mandatory spending on the dirty good consumption we have examined so far, the existence of the positive D* (and (D*/D)) has a role that limits the consumer's choices, regarding dirty-good consumption. Because of the positive level of mandatory dirty-good consumption, the consumer's choice range for the dirty-good consumption is somewhat limited. In other words, compared to the case in which D* is equal to zero, due to the minimum requirement consumption of the dirty good (D*), the consumer's choice of dirty good consumption (D) could not fully respond to the price change, which is caused by the newly established environmental tax.

In addition, this fact brings other quite important matters in analyzing the most important effect of the earlier general-equilibrium studies. The existence of a positive minimum requirement spending on the dirty good also upsets the tax-interaction effect that Bovenberg and de Mooij advocated. When there is positive amount of the D*, the necessary environmental tax rate to maintain the revenue neutrality is lower than the tax rate when D* is equal to zero. This means the tax base erosion of environmental tax is less severe than when the D* is equal to zero. In addition, now the force that pushes up the overall price (due to environmental tax) is less strong, and at the same time, the force that presses down the overall price (index) is increased, the level of the real wage is increased. Since the separability assumption is still in effect, the labor supply solely depends on the real wage, the higher real wage increases the labor supply, which implies the tax base of labor taxation is increased. Thus due to the existence of the positive D*, the tax-base erosion effect that Bovenberg and de Mooij advocated no longer holds.

Table V-3. Comparison of the Tax-Interaction Effect in terms of the percentage changes in Tax Base[45]

	Homothetic Utility			Non-Homothetic Utility		
Labor Tax Reduction	Real Wage rate	Tax Base of t_L	Tax Base of t_D	Real Wage rate	Tax Base of t_L	Tax Base of t_D
1%	-0.0311%	-0.004%	-3.376%	+0.198%	+0.044%	-2.905%
2%	-0.119%	-0.014%	-6.663%	+0.284%	+0.084%	-5.731%
3%	-0.263%	-0.030%	-9.859%	+0.376%	+1.198%	-8.47%

The next role of the minimum requirement of the dirty good consumption (D*) is about the tax efficiency of the environmental tax reform. The reason that Bovenberg and de Mooij advocate that it is very hard to expect the positive second dividend from an environmental tax reform is they find that the environmental taxation is less efficient than the labor taxation in revenue raising. However, the existence of positive level of mandatory consumption on the dirty good changes the character of the tax burden transfers. When the government imposes a new tax on the dirty good consumption, then the tax payment from consumer can be separated implicitly into two parts.

[45] (+) and (-) signs are stand for increasing and decreasing, respectively.
All changes are compares with the base case.

The tax on the mandatory spending on the dirty good consumption can be viewed as a lump-sum tax on the dirty good consumption, even though the form of the environmental tax is still a commodity tax. Since a lump-sum tax does not generate any first-order tax distortion, compared to the case in which the minimum requirement spending on the dirty good is zero, the overall tax burden of the environmental taxation is decreased. Thus, the existence of the minimum requirement of the dirty good consumption will reduce the tax burden of the environmental tax reform, and will enhance the tax efficiency of the tax system, so it supports the prospect of the double dividend.

V-4. Potential of The First Dividend

The reason that we perform the simulations that take into account the first dividend (Chapter II-2, Chapter III-3) is that the principal motivation for the environmental policies is as pollution-control policies rather than as policies that increase the efficiency of revenue raising[46]. Even though the current double dividend debate is concentrated on the second dividend, we should not neglect the core spirit of the (environmental) pollution-control studies.

Most economists agree with the positive aspect of the first dividend of the environmental tax reform. However, due to the nature of the first dividend (environmental quality improvement), the estimation of the first dividend is very hard, so many economists assume that the size of first dividend is generally unknown. Probably,

[46] Empirical studies show that environmental tax is used for raising revenue rather than changing behavior. See Hanley, Shogren, and White (1997)

the unknown size of the first dividend is the most important reason that economists concentrate more on the second dividend rather than the first dividend.

However, as mentioned, since the main reason that the government uses the environmental policy is correcting the environmental pollution, the consideration of the first dividend must be carried out at the same time. In this research, I try to measure the welfare effect of the first dividend by including a simple component into the simulation model that considers the first dividend. During the simulations in Chapter II and Chapter III, we confirm that the size of the first dividend is substantial. According to the simulation results in Chapter II, the first dividend is large enough to offset negative second dividend, so the environmental tax policy is still effective, even when there is no second dividend. Needless to say, when there is a positive second dividend, as we find in the chapter III-3, the environmental tax reform definitely improves the consumer's welfare and enhances the tax efficiency.

In summary, even though the estimation of the first dividend is hard, the environmental tax policy should not be considered abstract from the first dividend, because the main purpose of the environmental tax policy is controlling the environmental externality rather than effectiveness of the revenue raising.

V-5. Limitations and Further Research Plan

Even though the simulation models in Chapter III and Chapter IV lead us to a new conclusion about the double-dividend hypothesis, the models still have several limitations. In this subsection, I will discuss the limitations of this model, and I will suggest the further plan of this research, based on the limitations.

Probably the major limitation of this simulation model is the model is too simple for several points. First of all, the model employs a simple static analysis, without considering any dynamic analysis. Although the static model is easy to handle and gives a result that is relatively clear and straightforward, the dynamic analysis brings much more information of the new tax reform than does the simple static analysis. The second weakness of the model is that it has only two sectors in production. Obviously, compared to the other general-equilibrium simulation models, two sectors in production is too simple. In addition, it is highly stylized. The next weakness is regarding the production technology. Each industry in this model uses the labor as an only input and the production technology is linear one, which is very simple. Of course, the major reason that I use the simple linear technology along with only one input (labor) in production is to follow the assumption of Bovenberg and de Mooij. However, in any case, it seems that the linear technology with only one input is too simple. In addition, regarding the production technology, it does not contain intermediate production, which increases the degree of simplicity of the model.

Theses weaknesses are the major places that this research should be aimed for the further study. In order to strengthen the understanding of the double dividend issues, additional work should be done especially on the points that I mentioned above.

APPENDIX

Appendix-I. Detailed Algebra for the Homothetic Utility Function

1. Notes on the Algebra of the Consumer's Utility

In this appendix section, we will review the detailed algebra of the consumer's utility maximization problem. Since we use the assumption that the consumer does not consider the adverse effect of the dirty good consumption, the externality factor does not affect the consumer's choice. So in this appendix section, for convenience we will look at the model with the utility function that does not contain the externality factor.

The leisure/labor choice is characterized by the outer nest of the utility function, which is defined over leisure, *l*, and consumption of a composite good, X. The consumer's utility function takes the form

$$(A-1) \qquad U = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} +'(1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

where σ is the elasticity of substitution between leisure (l) and composite good X, and β is a weighting parameter.

The budget constraint indicates that the consumer's full income can be allocated to consumption of leisure or to consumption of goods.

$$(A-2) \qquad w'T = P_X X + w'l$$

where l is leisure consumption, X is consumption of the composite good, T is the time endowment for labor/leisure, w' is the net-of-tax price of leisure/labor, so (w' = w(1 – t_L)), and P_X is the price of consumption goods, including any taxes.

The Lagrangean function for the consumer's utility function is,

$$(A-3) \qquad \pounds = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} + \lambda(w'T - P_X X - w'l)$$

The first-order conditions of the choice variables (l,X) are,

$$(A-4) \qquad \frac{\partial \pounds}{\partial l} : \beta^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} l^{\frac{-1}{\sigma}} = \lambda w'$$

$$(A-5) \qquad \frac{\partial \pounds}{\partial X} : (1-\beta)^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} X^{\frac{-1}{\sigma}} = \lambda P_X$$

If we manipulate the prices, then (A-4) and (A-5) become,

$$(A-6) \qquad \beta^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} w'^{\frac{1-\sigma}{\sigma}} = \lambda w'^{\frac{1}{\sigma}} l^{\frac{1}{\sigma}}$$

$$(A-7) \qquad (1-\beta)^{\frac{1}{\sigma}} \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} P_X^{\frac{1-\sigma}{\sigma}} = \lambda P_X^{\frac{1}{\sigma}} X^{\frac{1}{\sigma}}$$

Inflate both sides of the equation (A-6) and (A-7) by σ, then

$$(A-8) \qquad \beta\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} w'^{1-\sigma} = \lambda^{\sigma} w' \; l$$

$$(A-9) \qquad (1-\beta)\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} P_X{}^{1-\sigma} = \lambda^{\sigma} P_X \; X$$

(A-8) + (A-9) will make equation (A-10).

$$(A-10) \qquad \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \left\{\beta w'^{1-\sigma} + (1-\beta) P_X{}^{1-\sigma}\right\} = \lambda^{\sigma}\left\{w' l + P_X X\right\}$$

From the first order conditions (A-4) and (A-5),

$$(A-11) \qquad \lambda = \frac{\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} \beta^{\frac{1}{\sigma}}}{w' l^{\frac{1}{\sigma}}}$$

$$(A-12) \qquad \lambda = \frac{\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} (1-\beta)^{\frac{1}{\sigma}}}{P_X X^{\frac{1}{\sigma}}}$$

By (A-10) and (A-11) we get the demand for the l.

$$(A-13) \qquad l = \frac{\beta \cdot I}{w'^{\sigma} \Delta} \quad ,$$

where $I = w'T$ (i.e., I is the consumer's "full income"), and

$$\Delta = \beta w'^{1-\sigma} + (1-\beta) P^{1-\sigma}.$$

Similarly, with (A-10) and (A-12) we have the demand for the composite consumption good X.

$$(A-14) \qquad X = \frac{(1-\beta)\cdot I}{P_X{}^{\sigma}\Delta}$$

Now, let's look at the consumer's innermost nest.

The inner nest of the consumer's utility function determines the allocation of the composite consumption good, X, between "clean goods"(C) and "dirty goods" (D). Good C is assumed not to generate an environmental externality, while good D does have a pollution externality. The inner nest of the utility function for goods consumption is:

$$(A\text{-}15) \qquad X = \left[\alpha^{\frac{1}{v}} D^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} C^{\frac{v-1}{v}}\right]^{\frac{v}{v-1}}$$

where v is the elasticity of substitution between the dirty good (D) and the clean good (C), and α is a weighting parameter on dirty good.

The budget constraint for the inner nest states that the consumer's net money income should be equal to the gross expenditure on the two goods:

$$(A\text{-}16) \qquad w'L = P_D' D + P_C' C$$

where, $P_D' = P_D(1+t_D)$, $P_C' = P_C(1+t_C)$.

We build up the Lagrangean function based on the equation *(A-15)* and *(A-16)*.

$$(A\text{-}17) \qquad \pounds = \left[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} + \lambda\,[\text{w'L} - \text{P}_\text{D}'\,\text{D} - \text{P}_\text{C}'\,\text{C}]$$

The first-order conditions of the choice variables are,

$$(A-18) \qquad \frac{\partial \pounds}{\partial D} : \alpha^{\frac{1}{\nu}} [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} D^{\frac{-1}{\nu}} = \lambda P'_D$$

$$(A-19) \qquad \frac{\partial \pounds}{\partial C} : (1-\alpha)^{\frac{1}{\nu}} [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} C^{\frac{-1}{\nu}} = \lambda P'_C$$

Next, manipulate the prices P_D' and P_C', so that both prices raised to the power $1/\sigma$ on the right-hand side

$$(A-20) \qquad \alpha^{\frac{1}{\nu}} [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} P'^{\frac{1-\nu}{\nu}}_D = \lambda P'^{\frac{1}{\nu}}_D D^{\frac{1}{\nu}}$$

$$(A-21) \qquad (1-\alpha)^{\frac{1}{\nu}} [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} P'^{\frac{1-\nu}{\nu}}_C = \lambda P'^{\frac{1}{\nu}}_C C^{\frac{1}{\nu}}$$

Raise both sides of equation (A-20) and (A-21) to the ν power:

$$(A-22) \qquad \alpha [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{\nu}{\nu-1}} P'^{1-\nu}_D = \lambda^\nu P'_D D$$

$$(A-23) \qquad (1-\alpha) [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{\nu}{\nu-1}} P'^{1-\nu}_C = \lambda^\nu P'_C C$$

(A-22) + (A-23) will build up the equation (A-24):

$$(A-24) \qquad [\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{\nu}{\nu-1}} \left\{\alpha P'^{1-\nu}_{D} + (1-\alpha) P'^{1-\nu}_{C}\right\} = \lambda^{\nu} \{P'_D D + P'_C C\}$$

From the first order conditions (A-18) and (A-19):

$$(A-25) \qquad \lambda = \frac{[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} \alpha^{\frac{1}{\nu}}}{P'_D D^{\frac{1}{\nu}}}$$

$$(A-26) \qquad \lambda = \frac{[\alpha^{\frac{1}{\nu}} D^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} C^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}} (1-\alpha)^{\frac{1}{\nu}}}{P'_C C^{\frac{1}{\nu}}}$$

Plugging (A-25) into (A-24) will generate the demand function for the dirty good D:

$$(A-27) \qquad D = \frac{\alpha \cdot I_X}{P^{w}_{D} \Omega}$$

where $I_X = w'L$ (= $P_D' D + P_C' C$) is net money income that is available to be spent on consumption goods, and $\Omega = \{\alpha P'^{1-\nu}_{D} + (1-\alpha) P'^{1-\nu}_{C}\}$.

Similarly, by (A-26) and (A-24) we get the demand function for the clean good C:

$$(A-28) \qquad C = \frac{(1-\alpha) \cdot I_X}{P^{w}_{C} \Omega}$$

We get the indirect utility function by inserting the demand functions (A-13), (A-14) into the utility function (A-1).

$$(A-29) \qquad V = I\left\{\beta w'^{1-\sigma} + (1-\beta)P_X^{1-\sigma}\right\}^{\frac{1}{\sigma-1}}$$

The income solution of the indirect utility function is the expenditure function.

$$(A-30) \qquad E = V\left\{\beta w'^{1-\sigma} + (1-\beta)P_X^{1-\sigma}\right\}^{\frac{1}{1-\sigma}}$$

Because the function we are dealing with now in this section is a homothetic function, we have a nice property of the function that expenditure equals utility multiplied by the ideal price index P*, where

$$(A-31) \qquad P^* = \left\{\beta w'^{1-\sigma} + (1-\beta)P_X^{1-\sigma}\right\}^{\frac{1}{1-\sigma}}$$

The welfare change is measured by equivalent variation (E.V.).

$$(A-32) \qquad EV = (V_b - V_r)P_b^*$$

where the subscripts b, r represent the base case and the revised case respectively.

Using the demand functions for the dirty good (D) (A-27) and the clean good (C) (A-28), we get the ideal price index for the X composite, P_X. Plugging (A-27) and (A-28) to (A-15).

$$(A-33) \qquad V_X = I_X\left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{v-1}}$$

Rearrange (A-34) with respect to the labor income (I_X), we have

$$(A-34) \qquad I_X = V_X\left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{1-v}}$$

Since the sub-utility function is also homothetic, as in the equation (A-31), we can use the special property of the homothetic utility function here again. So the ideal price index (P_X) for the composite good X is,

$$(A-35) \qquad P_X = \left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{1-v}}$$

2. Calibration Procedure

For having the desired level of the labor supply elasticities (η_c, η_u), we have to have suitable sets of the parameters which are consistent with the data and the functions of the model. The procedure used here is essentially the same as that in the Ballard (1990), but some modifications are made to be compatible with specific functional assumptions.

Repeating the equation for the leisure demand function (A-13), we have

$$(A-36) \qquad l = \frac{\beta \cdot I}{w'^{\sigma}\,\Delta}$$

$$\textit{where} \qquad I = w'T = P_X X + w'l$$

$$\Delta = \{\beta w'^{1-\sigma} + (1-\beta)P^{1-\sigma}\}$$

Rearrange (A-36), we have

$$(A-37) \qquad l w'^{\sigma}\,\Delta = \beta I$$

Totally differentiating with respect to w' will yields

$$(A-38) \qquad \frac{\partial l}{\partial w'} w'^{\sigma}\,\Delta + l\frac{\partial w'^{\sigma}}{\partial w'}\Delta + l w'^{\sigma}\frac{\partial \Delta}{\partial w'} = \beta\frac{\partial I}{\partial w'}$$

After some manipulations, we have a simple expression for the leisure demand elasticity, $\hat{\xi}$:

$$(A-39) \qquad \hat{\xi} = \frac{Tw'}{I} - \sigma - \frac{(1-\sigma)w'l}{I}$$

Solving for σ, we have

$$(A-40) \qquad \sigma = \frac{-\hat{\xi} + \left(\dfrac{w'T - w'l}{I}\right)}{1 - \dfrac{w'l}{I}}$$

The wage elasticity of leisure demand, $\hat{\xi}$, comes from the assumption about the ratio of l to T, and the labor supply elasticity. The ratio is also important in controlling the income elasticity, and therefore in controlling the compensated labor-supply elasticity. An iterative procedure is used to find the value of l/T for each of the uncompensated and compensated elasticity pairs for which simulations are performed.

Having the value of σ, now it is possible to solve for β. Dividing equation (A-14) by equation (A-13), we get

$$(A-41) \qquad \frac{X}{l} = \frac{(1-\beta)}{\beta} \frac{w^{*\sigma}}{P_X^{*\sigma}}$$

Rearranging (A-42) and solving for β, we have

$$(A-42) \qquad \beta = \frac{w^{\nu\sigma} l}{P_X^{\nu\sigma} X + w^{\nu\sigma} l}$$

To get the parameters that will correspond to any desired level of the compensated and uncompensated good demand elasticities (ε_c, ε_u), we also need to calibrate the inner nest of the consumer's utility function. Having the starting value of $\hat{\nu}$, we can get the weighting parameter of the dirty good consumption, α.

Divide equation (A-27) with equation (A-28), we have

$$(A-43) \qquad \frac{D}{C} = \frac{\alpha}{(1-\alpha)} \frac{P_C^{\hat{\nu}}}{P_D^{\hat{\nu}}}$$

Rearrange (A-43) and solve to α, then we have the expression for α:

$$(A-45) \qquad \alpha = \frac{DP_D^{\hat{\nu}}}{P_D^{\hat{\nu}} D + P_C^{\hat{\nu}} C}$$

By the iterative procedure, the calibration program will find suitable values for $\hat{\nu}$, and α for the desired level of the good demand elasticities.

Appendix-II. Detailed Algebra for the Non-Homothetic Utility Function

1. Notes on the Algebra of the Consumer's Utility

Now, we will examine the detailed algebraic process of the model with the non-homothetic utility function. The critical difference in our model between the homothetic and non-homothetic utility function is the inner nest of them. For relaxing the homotheticity assumption, we use the generalized C.E.S utility function with minimum requirements consumption of the clean (C*) and the dirty goods.

The inner nest of the consumer's utility function is,

$$(A\text{-}1) \qquad X = \left[\alpha^{\frac{1}{\nu}} (D - D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}} (C - C^*)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}$$

where ν is the elasticity of substitution between discretionary quantities of the dirty good (D) and the clean good(C),

α is a weighting parameter on dirty good,

D* is the minimum requirement of the dirty good consumption, and

C* is the minimum requirement of the clean good consumption.

Because of the requirement consumption, C* and D*, this function is not homothetic with respect to the origin, but homothetic with respect to the displaced origin (C*,D*).

The budget constraint is,

$$(A\text{-}2) \qquad w'L = P_D'\, D + P_C'\, C$$

where the prices include taxes, *i.e.*, $P_D' = P_D(1+t_D)$, $P_C' = P_C(1+t_C)$, $w' = w(1-t_L)$. Γ is the value of the minimum required level of consumption:

$$(A\text{-}3) \qquad \Gamma = P_D' D^* + P_C' C^*$$

We build the Lagrangean function with equation (A-1) and (A-2)

$$(A\text{-}4) \qquad £ = \left[\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}} \right]^{\frac{v}{v-1}} + \lambda\,(w'L - P_D'\,D - P_C'\,C)$$

The first-order conditions of the choice variables (C,D) are,

$$(A\text{-}5) \qquad \frac{\partial £}{\partial D} : \alpha^{\frac{1}{v}} [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{1}{v-1}} (D - D^*)^{\frac{-1}{v}} = \lambda P'_D$$

$$(A-6) \qquad \frac{\partial £}{\partial C} : (1-\alpha)^{\frac{1}{v}} [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{1}{v-1}} (C - C^*)^{\frac{-1}{v}} = \lambda P'_C$$

Manipulate the prices P'_D and P'_C, so that both prices are raised to the power 1/v on the right-hand side

$$(A-7) \qquad \alpha^{\frac{1}{v}} [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{1}{v-1}} P'^{\frac{1-v}{v}}_D = \lambda P'^{\frac{1}{v}}_D (D - D^*)^{\frac{1}{v}}$$

$$(A-8) \qquad (1-\alpha)^{\frac{1}{v}} [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{1}{v-1}} P'^{\frac{1-v}{v}}_C = \lambda P'^{\frac{1-v}{v}}_C (C - C^*)^{\frac{-1}{v}}$$

Inflate both sides to the v power:

$$(A-9) \qquad \alpha [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{v}{v-1}} P^{1-v}_D = \lambda^v P'_D (D - D^*)$$

$$(A-10) \qquad (1-\alpha) [\alpha^{\frac{1}{v}} (D - D^*)^{\frac{v-1}{v}} + (1-\alpha)^{\frac{1}{v}} (C - C^*)^{\frac{v-1}{v}}]^{\frac{v}{v-1}} P^{1-v}_C = \lambda^v P'_C (C - C^*)$$

(A-9) + (A-10) will build up the equation (A-11):

$$(A-11) \qquad [\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{\nu}{\nu-1}}\{\alpha P'^{1-\nu}_{D} + (1-\alpha)P'^{1-\nu}_{C}\}$$
$$= \lambda^{\nu}\{P'_D(D-D^*) + P'_C(C-C^*)\}$$

From the first order conditions (A-5) and (A-6):

$$(A-12) \qquad \lambda = \frac{\alpha^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}}}{P'_D(D-D^*)^{\frac{1}{\nu}}}$$

$$(A-13) \qquad \lambda = \frac{(1-\alpha)^{\frac{1}{\nu}}[\alpha^{\frac{1}{\nu}}(D-D^*)^{\frac{\nu-1}{\nu}} + (1-\alpha)^{\frac{1}{\nu}}(C-C^*)^{\frac{\nu-1}{\nu}}]^{\frac{1}{\nu-1}}}{P'_C(C-C^*)^{\frac{1}{\nu}}}$$

Replacing λ in equation (A-11) with (A-12) and (A-13) will give us the demand functions for the clean and the dirty goods:

$$(A-14) \qquad D = \frac{\alpha\{I_X - \Gamma\}}{P'^{\nu}_{D}\Omega} + D^*$$

$$(A-15) \qquad C = \frac{(1-\alpha)\{I_X - \Gamma\}}{P_C^{\nu}\Omega} + C^*$$

where $I_X - \Gamma$ (= w'L - P_D' D*- P_C' C*) is discretionary income, i.e., net money income minus mandatory spending on minimum required consumption (D*,C*), and $\Omega = \{\alpha P_D^{1-\nu} + (1-\alpha)P_C^{1-\nu}\}$.

Due to the requirements of the clean and the dirty goods consumption (C*,D*), the consumer's choice in the outer nest (choice of X and l) will be changed. The outer nest of the utility function will not be changed, but the consumer's budget constraint is:

$$(A\text{-}16) \qquad w'T = P_{XD}X + w'l + \Gamma$$

So, the Lagrangean function is:

$$(A-17) \qquad \pounds = \left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D{}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} + \lambda(w'T - P_{XD}X_D - w'l - \Gamma)$$

The first order conditions with respect to the choice variables (l,X_D) are,

$$(A-18) \qquad \frac{\partial \pounds}{\partial l} : \beta^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D{}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} l^{\frac{-1}{\sigma}} = \lambda w'$$

$$(A-19) \qquad \frac{\partial \pounds}{\partial X} : (1-\beta)^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D{}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} X_D{}^{\frac{-1}{\sigma}} = \lambda P_{XD}$$

Manipulate the prices w' and P_{XD}, so that both prices are raised to the power $1/\sigma$ on the right-hand side:

$$(A-20) \qquad \beta^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}} l^{\frac{\sigma-1}{\sigma}} + (1-\beta)^{\frac{1}{\sigma}} X_D{}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}} w'^{\frac{1-\sigma}{\sigma}} = \lambda w'^{\frac{1}{\sigma}} l^{\frac{1}{\sigma}}$$

Inflate both sides to the σ power:

$$(A-21) \qquad (1-\beta)^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}P_{XD}^{\frac{1-\sigma}{\sigma}}=\lambda P_{XD}^{\frac{1}{\sigma}}X_D^{\frac{1}{\sigma}}$$

$$(A-22) \qquad \beta\left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}w^{1-\sigma}=\lambda^{\sigma}w'l$$

$$(A-23) \qquad (1-\beta)\left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}P_{XD}^{1-\sigma}=\lambda^{\sigma}P_{XD}X_D$$

(A-22) + (A-23) will make the equation (A-24):

$$(A-24) \qquad \left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}\left\{\beta w^{1-\sigma}+(1-\beta)P_{XD}^{1-\sigma}\right\}=\lambda^{\sigma}\left\{w'l+P_{XD}X_D\right\}$$

From the first order conditions (A-18) and (A-19), reorganize both equations with respect to λ:

$$(A-25) \qquad \lambda=\frac{\beta^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}}{w'l^{\frac{1}{\sigma}}}$$

$$(A-26) \qquad \lambda=\frac{(1-\beta)^{\frac{1}{\sigma}}\left[\beta^{\frac{1}{\sigma}}l^{\frac{\sigma-1}{\sigma}}+(1-\beta)^{\frac{1}{\sigma}}X_D^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}}{P_{XD}X_D^{\frac{1}{\sigma}}}$$

Replacing λ in equation (A-24) with (A-25) and (A-26) will give us the demand functions for the leisure and the composite good (X):

$$(A-27) \qquad l = \frac{\beta \cdot I_D}{w'^{\sigma}\Delta}$$

$$(A-28) \qquad X_D = \frac{(1-\beta)\cdot I_D}{P_{XD}{}^{\sigma}\Delta}$$

where I_D is discretionary income, *i.e.*, I_D = w'T-Γ, $\Delta = \beta w'^{1-\sigma} + (1-\beta)P_{XD}{}^{1-\sigma}$

Since the process for the welfare evaluation system is similar to the case of the homothetic utility case (refer to the equations (A-29) to (A-33) in the section 1 of the appendix I), we will skip that. However, the important part is the process of getting the ideal price index for the composite good X_D (P_{XD}), under the non-homothetic utility.

Inserting the demand functions (equations (A-14) and (A-15)) into the inner nest of the utility function (A-1), we get the indirect utility function V_X:

$$(A-29) \qquad V_X = (I_X - \Gamma)\left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{v-1}}$$

Equation (A-29) is crucial since we can not use the nice property of the homothetic utility function, since the generalized CES utility function is not homothetic. Clearly the maximized value of the utility, V_X, can not be multiplied by any ideal price index to get I_X. In fact, the ideal price index for the generalized CES function is quite messy. However, if we neglect the expenditure on the mandatory consumption Γ, we have a homothetic relationship between discretionary income, I_{XD}, and the indirect utility from consumption in excess of the requirements:

$$(A-30) \qquad I_{XD} = I_X - \Gamma$$

Adopting (A-30) into our indirect utility function (A-29):

$$(A-31) \qquad V_X = I_{XD}\left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{v-1}}$$

This equation (A-31) suggests that we can use the ideal price index for the CES utility form (equation (A-36) in section1 of the appendix I), appropriately modified to include the generalized CES weights.

Then, rearrange (A-31) with respect to the discretionary income I_{XD}:

$$(A-32) \qquad I_{XD} = V_X\left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{1-v}}$$

So the ideal price index (P_{XD}) for the composite good out of discretionary income (X_D) is:

$$(A-33) \qquad P_{XD} = \left\{\alpha P'^{1-v}_D + (1-\alpha)P'^{1-v}_C\right\}^{\frac{1}{1-v}}$$

2. Calibration Procedure

Because the calibration procedure for the parameters that are consistent with the desired level of the labor supply elasticities is essentially the same as in the previous section (refer to the equations (A-37) to (A--43)), we will skip these parts. However, the non-homotheticity assumption will affect the process for the good demand elasticities. Here in this section, we will examine the calibration procedure.

To get the parameters that will correspond to any desired level of the uncompensated and compensated good demand elasticities, we need to calibrate the inner nest of the consumer's utility function. Once we have the starting value of $\hat{v}$, we can calculate the weighting parameter of the dirty good consumption, α.

We can modify the demand function for the clean and the dirty good, so we have (A-14') and (A-15')

$$(A-14') \qquad D - D^* = \frac{\alpha\{I_X - \Gamma\}}{P^{v}_{D}\,\Omega}$$

$$(A-15') \qquad C - C^* = \frac{(1-\alpha)\{I_X - \Gamma\}}{P^{v}_{C}\,\Omega}$$

Dividing equation (A-14') with equation (A-15') will yields equation (A-34).

$$(A-34) \qquad \frac{(D-D^*)}{(C-C^*)} = \frac{\alpha P^{v}_{C}}{(1-\alpha)P^{v}_{D}}$$

Rearrange equation (A-34) and solve α:

$$(A-35) \qquad \alpha = \frac{P^{v}_{D}(D-D^*)}{P^{v}_{D}(D-D^*) + P^{v}_{C}(C-C^*)}$$

By the iterative procedure, the calibration program will search the best values for $\hat{v}$ and α that are compatible with the desired level of the good demand elasticities.

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