ALTERNATIVE TAX INSTRUMENTS FOR CO_2 EMISSION REDUCTION AND EFFECTS OF REVENUE RECYCLING SCHEMES

GOVINDA R. TIMILSINA and RAM M. SHRESTHA

ABSTRACT

This study examines the roles of revenue recycling schemes for the selection of alternative tax instruments (i.e., carbon-, sulphur-, energy- and output-tax) to reduce CO_2 emissions to a specified level in Thailand. A static, single period, multi-sectoral computable general equilibrium (CGE) model of the Thai economy has been developed for this purpose. This study finds that the selection of a tax instrument to reduce CO_2 emissions would be significantly influenced by the scheme to recycle the tax revenue to the economy. If the tax revenue is recycled to finance cuts in the existing labour or indirect tax rates, carbon tax would be more efficient than the sulphur-, energy- and output-taxes to reduce CO_2 emissions. On the other hand, if the tax revenue is recycled to households through a lump-sum transfer, sulphur and carbon taxes would be more efficient than energy and output taxes. The ranking between the sulphur and carbon taxes under the lump sum transfer scheme depends on substitution possibility of fossil fuels. Sulphur tax is found superior over carbon tax at the higher substitution possibility between fossil fuels; the reverse is found true at the lower substitution possibility. In all schemes of revenue recycling considered, the output tax is found to be the most costly (i.e., in welfare terms) despite the fact that it generates two to three times higher revenue than the other tax instruments.

Keywords:
Computable general equilibrium analysis; environmental tax instruments; tax revenue recycling; carbon tax; sulphur tax; energy tax; output tax

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1. INTRODUCTION

There are a number of alternative tax instruments for reducing atmospheric emissions such as carbon dioxide (CO_2), sulphur dioxide (SO_2), oxides of nitrogen (NO_x). Among them, the more common are environmental taxes (e.g., carbon- and sulphur-tax), energy (or Btu) tax and output tax. Carbon and sulphur taxes are levies on fossil fuels in proportionate to contents of carbon and sulphur, respectively. An energy tax is applied in proportionate to heat contents of a fuel, whereas the output tax here is defined as a levy on the output of a good or service in proportionate to CO_2 emissions released during its production. Existing studies, such as Jorgenson and Wilcoxen (1993), Goulder (1994) and Schmutzler and Goulder (1997), have compared different taxes for the purpose of reducing environmental pollution. Goulder (1994) shows that an energy tax is less efficient than an income tax to generate the same amount of revenue. Jorgenson and Wilcoxen (1993) finds, among carbon-, energy- and output- taxes for reducing CO_2 emission, that the adverse impacts of the tax on the economy is the lowest in the case of carbon tax and highest in the case of the output tax. While comparing economic impacts of different tax instruments to reduce CO_2 emissions, existing studies (e.g., Jorgenson and Wilcoxen, 1993 and Goulder, 1994) consider only a particular scheme for recycling tax revenue[1] instead of considering alternative schemes of revenue recycling. A question may arise as to whether a carbon tax is always more efficient (i.e., in welfare terms) than other taxes (e.g., sulphur, energy and output taxes) to reduce CO_2 emissions irrespective of schemes to recycle the tax revenue. While an output tax is relatively more expensive than a carbon tax for reducing the same level of CO_2 emissions, it generates higher revenue than the carbon tax (Jorgenson and Wilcoxen, 1993 and Goulder, 1994).

An important issue often neglected in the environmental tax literature is the strong inter-linkage between the carbon and sulphur taxes. A carbon tax reduces not only CO_2 emission but also emissions of other pollutants (e.g., SO_2, NO_x). This is because a carbon tax would reduce demand for fossil fuels, particularly coal and oil, which are also the primary sources of SO_2 and NO_x emissions. Similarly, sulphur tax reduces not only SO_2 but also CO_2 and NO_x emissions. A question would then arise as to what extent carbon and sulphur taxes complements to each other in meeting their objectives. Could a sulphur tax be more efficient than a carbon tax to reduce CO_2 emissions? If yes, would the results be sensitive to revenue recycling schemes? Interestingly, our analysis shows that, in the case of Thailand, sulphur tax could be more preferable than carbon tax to reduce CO_2 emission when the tax revenue is recycled to households through a lump sum transfer. This is mainly because of the use of low quality coal (i.e., high sulphur content and low heat value) which accounts for about one third of total fossil fuel based energy consumption in the country.

The paper contributes into the literature in two fronts. First, it compares alternative environmental tax instruments under alternative revenue recycling schemes, which is different from the existing practice of ranking of tax instruments under a particular scheme of tax revenue recycling. Secondly, it examines complementarities between sulphur and carbon taxes to reduce CO_2 emissions. It further investigates sensitivities of the carbon and sulphur tax relationship, first to tax revenue recycling schemes, and second to various degree of substitution possibility between energy commodities. The study considers four different tax instruments (i.e., carbon-, sulphur-, energy- and output-tax) and three alternative schemes for

[1] Jorgenson and Wilcoxen (1993) considers lump-sum transfers of tax revenue to households, while Goulder (1994) considers recycling of tax revenue to replace personal income taxes.

recycling tax revenue[2]. The revenue recycling schemes considered here are: (i) recycling the tax revenue to households through a lump sum transfer (hereafter "Scheme 1"), (ii) using it to finance cuts in existing labour tax rate (hereafter "Scheme 2") and (iii) using it to finance cuts in existing indirect tax rates of non-energy goods (hereafter "Scheme 3").

The paper is organized as follows: Section 2 presents the computable general equilibrium model developed for the purpose of the study followed by the presentation of data and model parameters. Section 4 presents results from the simulations of the main analysis while Section 5 presents the results of sensitivity analyses. Finally, the conclusions and final remarks are presented.

2. THE CGE MODEL

The model developed here is a static, single period, multi-sectoral computable general equilibrium model of the Thai economy. In this section, we present approaches and assumptions used to model various economic agents, such as producers, households, government and foreign sectors.

2.1 Production sector

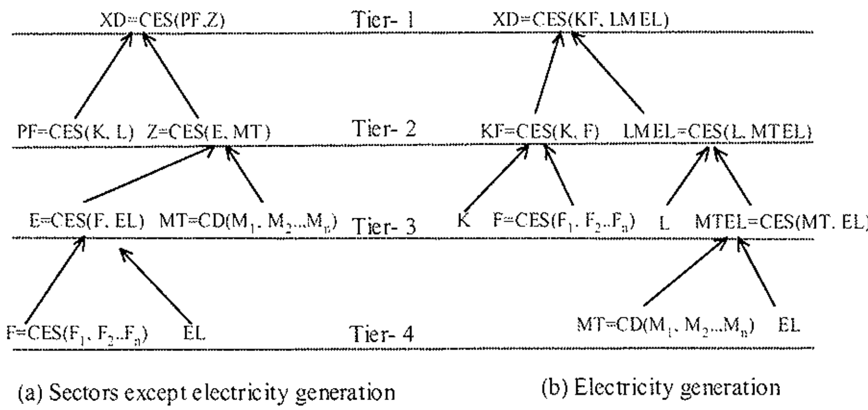
The economy is disaggregated into 21 production sectors of which 6 are energy sectors (see Table 1). Production behaviour of each sector is represented by nested constant elasticity of substitution (CES) production functions. This is along the lines of some existing studies (e.g., Bohringer and Rutherford, 1997; Capros et al., 1997 and Bovernberg and Goulder, 1996). The model developed here, however, differs from existing ones while representing the electricity sector. First, the electricity sector is divided into seven sub-sectors based on technologies used for electricity generation. This allows the substitution possibilities between various technologies used for electricity generation. Most existing studies, in contrast, treat electricity sector as a single technology thereby restricting such substitution possibilities. Secondly, the nested CES structure used for the electricity sector differs from those used in the rest of the sectors to allow direct substitution between capital and fuel in the electricity generation industry. Our model considers the gross output of the electricity sector as a CES function of the capital-fuel composite and the labour-material-electricity composite in contrast to the existing practice of treating it as a function of primary factor composite (i.e., a composite of capital and labour) and the aggregate intermediate input.

Figures 1a and 1b present the nested production structures, respectively for the electricity sector and other sectors.

As can be seen from these figures, for all sectors except electricity generation, gross output (XD) is a CES function of the primary factor composite (PF) and the aggregate intermediate input (Z).

[2] Different countries recycle government revenues to consumers through different schemes such as cash transfers, tax credits, subsidy to essential commodities such as food, medicine (Coady and Harris, 2004).

Figure 1: Nested Structure of Production Sector



CES refers to a constant elasticity of substitution functional form and CD refers to a Cobb-Douglas functional form, XD represents gross output, PF and Z refer to the primary factor composite and the aggregate intermediate consumption; K, L, E and MT refer to capital, labour, the aggregate energy consumption and the aggregate material consumption; F, EL and M refer to fuel, electricity and material. Similarly, KF, LMEL and MTEL refer to the capital fuel composite, the labour, material, electricity composite and the material and electricity composite.

In the electricity sector, gross output is a CES function of the capital-fuel composite (KF) and the labour-material-electricity composite (LMEL). The gross output is expressed as follows:

$$(1)\quad XD_i = [\alpha_{PF_i}^{1/\sigma_i^{PFZ}} . PF_i^{(\sigma_i^{PFZ}-1)/\sigma_i^{PFZ}} + \alpha_{Z_i}^{1/\sigma_i^{PFZ}} . Z_i^{(\sigma_i^{PFZ}-1)/\sigma_i^{PFZ}}]^{\sigma_i^{PFZ}/(\sigma_i^{PFZ}-1)}$$

$i \neq$ electricity sector

$$(2)\quad XD_g = [\alpha_{KF_g}^{1/\sigma_g^{KFLMEL}} . KF_g^{(\sigma_g^{KFLMEL}-1)/\sigma_g^{KFLMEL}} + \alpha_{LMEL_g}^{1/\sigma_g^{KFLMEL}} . LMEL_g^{(\sigma_g^{KFLMEL}-1)/\sigma_g^{KFLMEL}}]^{\sigma_g^{KFLMEL}/(\sigma_g^{KFLMEL}-1)}$$

$g =$ electricity sub-sector

where α_{PF} and α_Z represent scaling factors for PF and Z, respectively and σ^{PFZ} is the elasticity of substitution between PF and Z. In the electricity sector PF, Z, α_{PF}, α_Z and σ^{PFZ} are respectively replaced by KF, LMEL, α_{KF} (i.e., scaling factor for KF), α_{LMEL} (i.e., scaling factor for LMEL) and σ^{KFLMEL} (i.e., elasticity of substitution between KF and LMEL). PF, KF, Z and LMEL are derived as follows:

$$(3)\quad PF_i = \alpha_{PF_i} . XD_i . (\frac{xdp_i}{pfp_i})^{\sigma_i^{PFZ}}$$

(4) $Z_i = \alpha_{Z_i} .XD_i .(\frac{xdp_i}{zp_i})^{\sigma_i^{PFZ}}$

i ≠ electricity sector

(5) $KF_g = \alpha_{KF_g} .XD_g .(\frac{xdp_g}{kfp_g})^{\sigma_g^{KFLMEL}}$

(6) $LMEL_g = \alpha_{LMEL_g} .XD_g .(\frac{xdp_g}{lmelp_g})^{\sigma_g^{KFLMEL}}$

g = electricity sub-sector

where xdp, pfp and zp are price of the gross output, the primary factor composite and the aggregate intermediate good, respectively. In the electricity sub-sectors, pfp, zp, α_{PF}, α_Z and σ^{PFZ} are replaced by, respectively, kfp (i.e., price of KF), lmelp (i.e., price of LMEL), α_{KF}, α_{LMEL} and σ^{KFLMEL}.

The dual functions of Equation 1 and 2 give the unit cost of production as follows:

(7) $xdp_i = [\alpha_{PF_i} .pfp_i^{(1-\sigma_i^{PFZ})} + \alpha_{Z_i} .zp_i^{(1-\sigma_i^{PFZ})}]^{1/(1-\sigma_i^{PFZ})}$

i ≠ electricity sector

(8) $xdp_g = [\alpha_{KF_g} .kfp_g^{(1-\sigma_g^{KFLMEL})} + \alpha_{LMEL_g} .lmelp_g^{(1-\sigma_g^{KFLMEL})}]^{1/(1-\sigma_g^{KFLMEL})}$

g = electricity sub-sector

In the similar manner for Equations 3 to 6, all other demand variables presented in the subsequent tiers of the nested structures in Figs. 1a and 1b are derived except for the material inputs (M_k). In the case of material input, the Cobb-Douglas functional form is considered, mainly due to a lack of substitution elasticities among the material inputs[3]. The demands for material input in production sector i ($M_{k,i}$) and electricity sub-sector g ($M_{k,g}$) are derived as follows:

[3] Despite an exhaustive literature survey, elasticity of substitution between materials could not be found for economies similar to Thailand; hence, we could not use CES functional form to model demands for material goods. Instead, we used Cobb-Douglas functional form that assumes unitary elasticity of substitution; which is a limitation. Nevertheless, the use of Cobb-Douglas functional form is common in CGE modeling.

$$(9)\quad M_{k,i} = \alpha_{k,i} \cdot \frac{MT_i . mtp_i}{gp_k .(1 + indt_k)}$$

i = sectors except the electricity sector

$$(10)\quad M_{k,g} = \alpha_{k,g} \cdot \frac{MT_g . mtp_g}{gp_k .(1 + indt_k)}$$

g = electricity sub-sectors

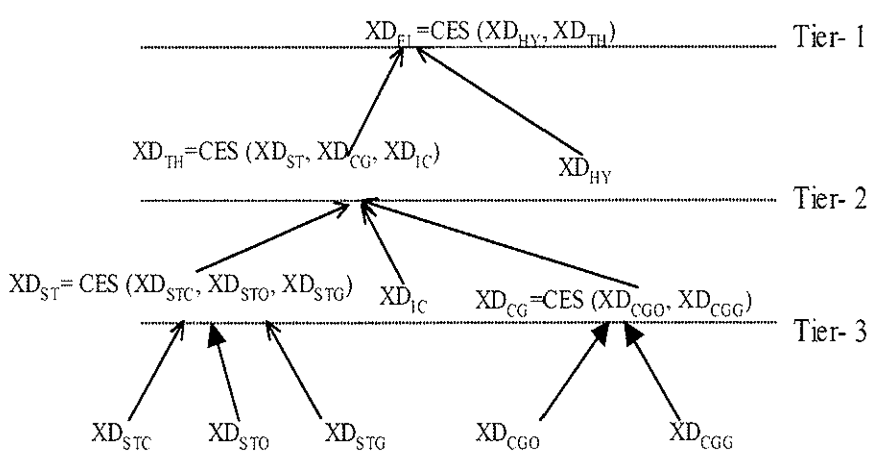
where, MT_i and MT_g are the aggregate material input in sector i and electricity sub-sector g, respectively; mtp is the price of MT; gp_k is the price of good k, $indt_k$ is indirect tax rate of good k and α is the share parameter. The price variables corresponding to all tiers except tier for material aggregation are derived in the similar manner for Equations 7 to 8. The prices of aggregate material input in production sectors i (mtp_i) and electricity sub-sectors g (mtp_g), are derived as follows:

$$(11)\quad mtp_i = \prod_k \left(\frac{gp_{k,i} .(1 + indt_k)}{\alpha_{k,i}}\right)^{\alpha_{k,i}}$$

$$(12)\quad mtp_g = \prod_k \left(\frac{gp_{k,g} .(1 + indt_k)}{\alpha_{k,g}}\right)^{\alpha_{k,g}}$$

The electricity sector is disaggregated into nine sub-sectors as shown in Fig. 2.

Figure 2: Disaggregation of the Electricity Sector



XD represents gross output, the subscripts HY, TH, ST, CG, IC refer to hydro, thermal, steam turbine, combined cycle and internal combustion engine; the subscripts STC, STO, STG refer to coal fired steam turbine, oil fired steam turbine and gas fired steam turbine; subscripts CGO and CGG refer to oil fired combined cycle and gas fired combined cycle.

The total electricity output (XD_{EL}) at the highest tier in the figure is a CES aggregate of hydro electricity (XD_{HY}) and thermal electricity (XD_{TH}) and can be expressed as:

$$(13) \quad XD_{EL} = [\alpha_{HY}^{1/\sigma^{HT}} .XD_{HY}^{(\sigma^{HT}-1)/\sigma^{HT}} + \alpha_{TH}^{1/\sigma^{HT}} .XD_{TH}^{(\sigma^{HT}-1)/\sigma^{HT}}]^{\sigma^{HT}/(\sigma^{HT}-1)}$$

where α_{HY} and α_{TH} are scaling factors and σ^{HT} is elasticity of substitution between hydro and thermal electricity. In the similar manner for Equations 3 to 6, XD_{HY} and XD_{TH} are derived as follows:

$$(14) \quad XD_{HY} = \alpha_{HY} .XD_{EL} .(\frac{xdp_{EL}}{xdp_{HY}})^{\sigma^{HT}}$$

$$(15) \quad XD_{TH} = \alpha_{TH} .XD_{EL} .(\frac{xdp_{EL}}{xdp_{TH}})^{\sigma^{HT}}$$

where, xdp_{EL}, xdp_{HY}, xdp_{TH} are the average costs of producing XD_{EL}, XD_{HY}, XD_{TH}, respectively. The average cost of producing electricity at the power system level or the producer's price under the constant returns to scale can be obtained from the dual function of Equation 13; this can be expressed as follows:

$$(16) \quad xdp_{EL} = [\alpha_{HY} .xdp_{HY}^{(1-\sigma^{HT})} + \alpha_{TH} .xdp_{TH}^{(1-\sigma^{HT})}]^{1/(1-\sigma^{HT})}$$

All demand variables presented in Figure 2 are derived in the similar manner for Equations 14 and 15, while all corresponding price variables are derived in the similar manner for Equation 16.

2.2. Household sector

This study considers a representative household that follows a five-step hierarchical optimisation process to maximise its utility (see Figure 3).[4] At the top of the hierarchy, the representative household trades off between savings (or future consumption) and the present consumption[5] while maximising utility (U), which is represented as follows:

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[4] A similar approach has been used in a number of existing general equilibrium models (e.g., Jorgenson and Wilcoxen, 1993a; Bohringer and Rutherford, 1997; Shoven and Whalley, 1992 and Ballard et al., 1985).

[5] The present consumption is the aggregation of goods, services and leisure consumed. According to Jorgenson and Wilcoxen (1993a), this is also referred to as full consumption.

$$(17)\quad U = [\alpha_{FC}^{1/\sigma^{FCS}}.FC^{(\sigma^{FCS}-1)/\sigma^{FCS}} + (1-\alpha_{FC})^{1/\sigma^{FCS}}.S^{(\sigma^{FCS}-1)/\sigma^{FCS}}]^{(\sigma^{FCS}-1)/\sigma^{FCS}}$$

where α_{FC} is the scaling factor and σ^{FCS} is the elasticity of substitution between the present consumption (FC) and household savings (S). FC and S are derived from the first order condition of utility maximisation (i.e., Equation 17) under budget constraint, $I = FC.fcp + S.sp$, as follows:

$$(18)\quad FC = \alpha_{FC}.I/(fcp^{\sigma^{FCS}}.\omega)$$

$$(19)\quad S = (1-\alpha_{FC}).I/(sp^{\sigma^{FCS}}.\omega)$$

where $\omega = \alpha_{FC}.fcp^{1-\sigma^{FCS}} + (1-\alpha_{FC}).sp^{1-\sigma^{FCS}}$; fcp and sp are prices of present consumption and savings, respectively and I is the full consumption. While the present consumption is a function of consumption of goods/services and leisure as illustrated in Figure 3, household savings is a function of the price of savings and the elasticity of substitution between present consumption and future consumption. Price of savings is equal to expected rate of return on investment. Investment is calculated in Equation 38 later. Note that the summation of household savings, government savings and foreign savings is equal to the total investment in the economy.

The full consumption (I) is the sum of disposable income (DI) and imputed value of leisure, i.e.

$$(20)\quad I = DI + wr.LS$$

where wr is real wage rate and LS is leisure demand. The price of utility (up) can be derived as a dual to the Equation 17 as follows:

$$(21)\quad up = (\alpha_{FC}.fcp^{1-\sigma^{FCS}} + (1-\alpha_{FC}).sp^{1-\sigma^{FCS}})^{\frac{1}{1-\sigma^{FCS}}}$$

Most general equilibrium models are found to use Hicksian equivalent variation to measure welfare impact of policy change (e.g., Ballard et al. 1985, Capros et al. 1997; Zhang, 1997). Hicksian equivalent variation is defined as the additional income necessary to obtain a new utility level at the old price. In terms of monetary value, the equivalent variation (EV) due to a policy shift can be expressed as follows:

$$(22)\quad EV = E(U^a, up^0) - E(U^0, up^0)$$

where U^a and U^0 are household utilities after and before the policy change, respectively; and up^0 is the price of utility before the policy change. Note here that the welfare effect does not account for the welfare improvements due to mitigation of carbon and sulphur emissions.

In the same manner for Equations 18 and 19, household demand for goods and services

(C) and leisure (LS) are derived from tier 2 of the nested structure in Fig. 3. Similarly, the household consumption of the aggregate material good (HMT) and the aggregate energy good (HEN) are derived from the third tier, followed by derivation of household demand for electricity (CH_{EL}), the fossil fuel aggregate (HF) at tier 4. At the bottom tier, household demand for fuels, CH_f (i.e., f = coal, oil, gas and fuel wood), are derived in the similar manner. The household demands for individual material, CH_k (see right hand side of tier 4 in Fig. 3) are derived by using a Cobb-Douglas functional form as follows:

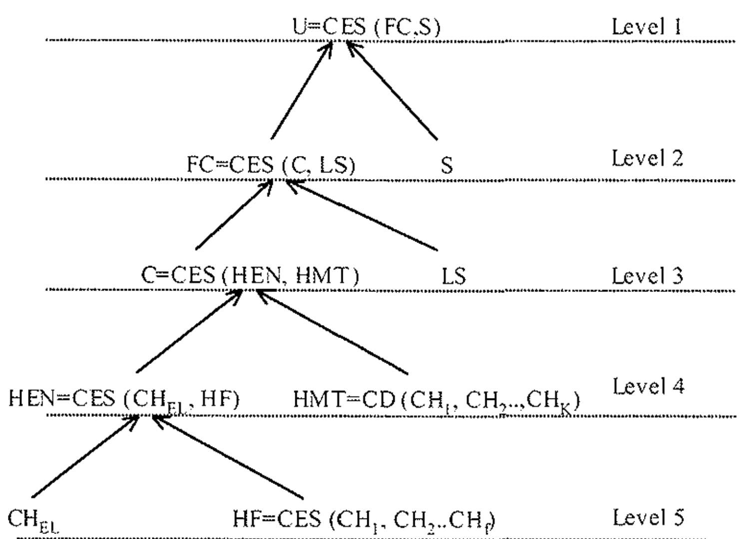
$$(23) \quad CH_k = \alpha_k^H . \frac{HMT.hmtp}{gp_k.(1+indt_k)}$$

where hmtp is the price of aggregated consumption of material goods in households, gp_k is the price of material good k.

The price variables corresponding to demand variables in Fig. 3 are derived in the similar manner for Equation 21, except for hmtp, which is given as follows:

$$(24) \quad hmtp = \prod_k \left(\frac{gp_k.(1+indt_k)}{\alpha_k^H}\right)^{\alpha_k^H}$$

Figure 3: Nested Structure for the Household Sector



U represents the household utility, FC and S refer to full consumption and savings; C and LS refer to the aggregate goods/service consumption and leisure; HEN, HF, HMT and CH refer to the aggregate energy consumption, the aggregate fuel consumption, the aggregate material consumption; and the individual goods/service consumption; subscript EL refers to electricity.

Total household income consists of capital income, labour income and the net transfer from the rest of the world. Capital income also includes depreciation. Labour income consists of not only salary and wages but also social security benefits to household. Total household income (THI) is expressed as follows:

$$\text{(25)} \quad THI = \sum_i [K_i.kp_i.(1+\tau^K) + L_i.wr.(1+\tau^L)] + NTRH$$

where kp is net capital price, τ^K and τ^L are capital tax rate and labour tax rate respectively, and NTRH is the net transfer from the rest of the world to the household and expressed as a fixed portion of total export demand as follows:

$$\text{(26)} \quad NTRH = a^{NTRH}.\sum_i EX_i.xdp_i$$

with a^{NTRH} as a ratio of NTRH to exports in the base case. Household income is subjected to income tax (ITAX), which is given as follows:

$$\text{(27)} \quad ITAX = \sum_i (K_i.kp_i.\tau^K + L_i.wr.\tau^L)$$

Disposable income of the household (DI) is total household income less income tax paid by the household and is given by:

$$\text{(28)} \quad DI = THI - ITAX$$

2.3 The government sector

While modeling the government sector, we assume that government consumption does not provide any utility to private consumers. This approach is commonly employed in several general equilibrium studies (e.g., Ballard et. al 1985; Capros et al. 1997; Zhang, 1997)[6]. Government collects tax, consumes public goods, saves part of its income and receives transfers from the rest of the world[7]. Total government revenue (GI) consists of indirect tax paid by firms, direct tax paid by households, import duty and net transfers from the rest of the world (NTRG), and is given as follows:

$$\text{(29)} \quad GI = ITAX + \sum_i [G_i.gp_i.indt_i + G_i^M.mp_i.impt_i] + NTRG$$

where G and G^M are total domestic demand and import demand, mp import price and impt is import duty. Net transfer from the rest of the world to the government is maintained at a fixed fraction of total exports as given below:

[6] It is possible to account government consumption in private utility if its contribution in the private utility (i.e., share of government consumption in total household utility) is known.

[7] On the contrary, existing studies particularly, McKibbin et al. (1999), Goulder et al. (1999), Parry et al. (1999) and Goulder (1995) assume that government neither consumes nor saves, it rather transfers all its income to households.

(30) $$NTRG = a^{NTRG}.\sum_j EX_j.xdp_j$$

with a^{NTRG} as a ratio of NTRG to exports in the base case and kept fixed in the simulation cases as well. Government income is allocated to public consumption and government savings. The government consumption of good i (CG_i) is kept the same as before the introduction of the carbon tax (i.e., CG^0_i). Government saving (SAVG) is the difference between the total government income and the total government consumption, i.e.,

(31) $$SAVG = GI - \sum_i CG_i.gp_i.(1+indt_i)$$

2.4 Foreign trade

Import demand: Following Armington (1969), we assume domestically produced and imported goods to be imperfect substitutes. The total demand for a good G_i is assumed to be a CES composite of its domestic components (G^D_i) and imported components (G^M_i) and expressed as follows:

(32) $$G_i = [\alpha_{D_i}^{1/\sigma_i^{DM}}.G_i^{D(\sigma_i^{DM}-1)/\sigma_i^{DM}} + \alpha_{M_i}^{1/\sigma_i^{DM}}.G_i^{M(\sigma_i^{DM}-1)/\sigma_i^{DM}}]^{\sigma_i^{DM}/(\sigma_i^{DM}-1)}$$

where α_{Di} and α_{Mi} are scaling factors of G^D_i and G^M_i; and σ^{DM}_i is the elasticity of substitution between G^D_i and G^M_i. G^D_i and G^M_i are derived as follows:

(33) $$G_i^D = \alpha_{D_i}.G_i.(\frac{gp_i}{xdp_i})^{\sigma_i^{DM}}$$

(34) $$G_i^M = \alpha_{M_i}.G_i.(\frac{gp_i}{mp_i})^{\sigma_i^{DM}}$$

where gpi is the price of the composite of domestically produced and imported good i, and mpi is the price of imported good i. The dual function of Equation 32 is used to derive gpi and it is given as follows:

(35) $$gp_i = [\alpha_{D_i}.xdp_i^{(1-\sigma_i^{DM})} + \alpha_{M_i}.mp_i^{(1-\sigma_i^{DM})}]^{1/(1-\sigma_i^{DM})}$$

With the assumption of small economy, the price of imported good is given by

(36) $$mp_i = gpw_i.ER.(1+impt_i)$$

where, gpw_i is the world price of good i, and ER is the exchange rate. Note that gpw_i and ER are exogenous (and fixed) in this study.

Export demand: Following a number of studies (e.g., Dervis et al. 1982; Shoven and Whalley, 1992, Capros et al., 1997; Naqvi, 1998), the model considers an explicit export demand function as follows:

$$(37) \quad EX_i = \alpha_i^{EX}.(\frac{gpw_i.ER}{xdp_i})^{\varepsilon_i}$$

where, α_i^{EX} is the share of good i in total export demand and ε_i is the price elasticity of exported good[8] i; (i.e., elasticity of export good i with respect to the world price). This export demand function is derived assuming that the world as a whole behave in a manner similar to the single country modeled and consumes products according to rules of cost minimization subject to the generalized CES formulation that specifies composite world commodities (Dervis et al. 1982)[9]. Our model rules out the possibility of direct exporting of the imported goods [i.e., "cross-hauling" (Shoven and Whalley, 1992)].

2.5 Investment Demand

The model considers that the total current investment demand in an economy is equal to the total delivery of investment goods to the economy in the previous year. The current investment demanded by the sector i (INV_i) is given as follows:

$$(38) \quad INV_i = K_i.[(\frac{kp_i}{invp_i.(ir + dpr)})^{\sigma_i^{XD}}.(1 + gr) - (1 - dpr)]$$

where, $invp_i$ is price of investment in sector i; 'ir', 'dpr' and 'gr' are interest rate, depreciation rate and growth rate of sectoral production, respectively. Though rate of depreciation and production growth rates can vary across the sectors, the model assumes them the same for all the sectors. The model assumes an optimal capital price, which is linked to the price of investment as follows:

$$(39) \quad kp_i = invp_i.(ir + dpr)$$

Delivery of investment good i ($INVD_i$) is assumed to be a fixed share of total investment goods delivered to the economy.

$$(40) \quad INVD_i = ANINV_i.\sum_i INV_i$$

where, $ANINV_i$ is the share of investment demanded by sector i in total investment demand.

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[8] As a price elasticity of demand is negative, ε in fact is the negative of the price elasticity of export.

[9] Some general equilibrium models developed for developing countries (e.g., Zhang, 1997; Xie 1996) have used an export supply function by using a constant elasticity of transformation (CET) function for this purpose. However, this requires estimation of additional parameters. Hence, this study models the export demand function instead of an export supply function.

2.6 Market clearing

Good market clearing: Total production of good i is the sum of the domestic consumption of domestically produced good and exported good.

(41) $$XD_i = G_i^D + EX_i$$

Total domestic demand consists of intermediate (ZA) and final demand (i.e., household consumption CH, government consumption CG, capital goods, INVD and inventory goods, STK).

(42) $$G_i = ZA_i + CH_i + CG_i + INVD_i + STK_i$$

Inventory demand for good i (STK_i) is maintained as a fixed fraction of output from sector i before and after the carbon tax.

(43) $$STK_i = a_i^{STK}.XD_i$$

where a_i^{STK} is the ratio of the stock of good i to its production in the base case, and it is kept fixed in the policy simulations cases as well.

Factor markets clearing: It is assumed that total time endowment (i.e., the active population) in the economy does not change due a policy change. This assumption implies that the total labour supply to the economy depends on the wage rate and labour supply elasticity. Following the Walrasian approach, it is assumed that the total labour supply (TLS) in the economy is equal to the total demand of labour in the economy. This gives us the following relationship:

(44) $$TLS = \sum_j L_j = TTE - LS$$

where TTE is the total time endowment of the work force in the economy and LS is the leisure demand. This implies that people who are legally eligible to work spend their time either working or consuming leisure.

The model allows capital mobility across the production sectors. However, the total capital stock (TK) in the economy is assumed to be unchanged as a result of a policy change. This implies the following relationship:

(45) $$\sum_i K_i = TK$$

Current Balance: The difference between total value outflow (e.g., imports of goods and services) from the country to the total value inflow (e.g., exports and transfers from the rest of the world) to the country is defined as the current balance (TBAL) and is expressed as:

(46) $$TBAL = [\sum_{j} M_j.mp_j - EX_j.xdp_j] - NTRH - NTRG$$

Macroeconomic balance: Total investment is the sum of total savings comprising of household saving, government saving and the current balance. This balance is an identity reflecting the Walras law and this equation is not necessary to solve the model.

(47) $$S.invp + SAVG + TBAL = \sum_{j} (INVD_j. + STK_j).gp_j$$

2.7 Emission estimation

Emissions of a pollutant p from sector n ($POL_{n,p}$ with p = CO_2, SO_2 and NO_x) can be estimated as follows:

(48) $$POL_{n,p} = \sum_{f} FF_{f,n}.c_f.ef_{f,p}$$

where n represents 20 industrial sectors (except the electricity sector), the household sector and the government sector; $FF_{f,n}$ refers to use of fossil fuel f (in monetary unit) in sector n; c_f converts FF_f to energy unit (e.g., GJ) and can be expressed as GJ/$; and $ef_{f,p}$ is the emission factor of pollutant p for fuel f, expressed in kg of pollutant per GJ unit fuel consumption (i.e., kg/GJ). Emissions of a pollutant p from electricity sub-sector g ($POL_{g,p}$) (p = CO_2, SO_2 and NO_x) can be estimated as follows:

(49) $$POL_{g,p} = XD_g.c_g.ef_{g,p}$$

where XD_g is electricity generation from technology type g (in monetary unit), c_g converts XD_g to energy unit (i.e., GWh) and $ef_{g,p}$ is the emission factor of pollutant p for generation technology g expressed in ton of pollutant per GWh electricity generation. Total emission of pollutant p from the electricity sector ($POL_{n,p}$ with n = electricity sector) is given as:

(50) $$POL_{n,p} = \sum_{g} POL_{g,p}$$

Total national level emission of pollutant p ($TPOL_p$) is given as:

(51) $$TPOL_p = \sum_{n} POL_{n,p}$$

where n represents 21 sectors including the electricity sector, the household sector and the government sector.

2.8 Policy Simulation

***Introduction of new tax instruments*:** The new tax, $etax_p$ (representing carbon tax if p is CO_2 and sulphur tax if p is SO_2) is exogenous to the model. Based on the given level of an environmental tax, an equivalent indirect tax (envt) is calculated as follows:

$$(52) \qquad envt_{f,p} = \frac{etax_p.POL^0_{f,p}}{(G^0_f - STK^0_f).gp^0_f}$$

$f \neq$ fuelwood.

where, $POL^0_{f,p}$ is emission of pollutant p from total consumption of fuel f in the country in the base case (i.e., before the introduction of an environmental tax). Note also that fuel wood is exempted from the environmental tax. The equivalent indirect tax for energy tax is calculated by replacing Equation 52 by the following equation:

$$(53) \qquad envt_f = \frac{BTAX}{COSTGJ_f}$$

f = coal, oil and gas

where $envt_f$ is the equivalent indirect tax of the energy or btu tax (BTAX), which is expressed in dollars per gigajoule (GJ), and $COSTGJ_f$ is cost of fuel f per unit of heat measured in GJ. Similarly, in the case of output tax, the equivalent indirect tax rates ($envt_i$) are calculated as follows:

$$(54) \qquad envt_i = \frac{POL^0_{i,p}.etax_p}{(G^0_i - STK^0_i).gp^0_i * 10^6}$$

$p = CO_2$

Please note the difference between Equations 52 and 54; the subscript f in Equation 52 is replaced with i in Equation 54, meaning that a carbon or sulphur tax is applied only to fossil fuels in Equation 52, whereas the output tax is applied to all goods and services in Equation 54. The carbon and sulphur taxes are direct taxes as they apply to only fossil fuels in proportionate to their carbon and sulphur contents. On the other hand, the output taxes are indirect taxes and they are applied to all goods and services in proportionate to the release of CO_2 emissions during their production. In order to generate output tax rates, an arbitrary carbon tax rate, $etax_p$ (US$ per ton of carbon emission) is used. The value of $etax_p$ is changed until the required output tax rates are generated to meet the emission reduction target (here 10% of CO_2 reduction).

The new indirect tax rate ($indt_i^{NEW}$) is the sum of indt and envt, i.e.,

$$(55) \quad indt_i^{NEW} = indt_i^0 + envt_i$$

where $indt_i^0 = \dfrac{ITAX_i^0}{G_i^0 . gp_i^0}$

$indt^0_i$ is the indirect tax rate of good i in the base case, which was calibrated as the ratio of total indirect tax paid by the good ($ITAX^0_i$) to the total sales of the good in the economy.

Revenue recycling: Three schemes for recycling tax revenue are considered in the study. These schemes are incorporated in the model as follows:

(i) *Recycling of tax revenue to households through a lump-sum transfer*: When the tax revenue is recycled to the households through a lump-sum transfer, Equation 25 is now replaced by the following equation:

$$(56) \quad THI = \sum_i [K_i .kp_i .(1 + \tau^K) + L_i .wr.(1 + \tau^L)] + NTRH + REVGAP$$

$$(57) \quad REVGAP = GI - GI^0$$

GI is the total government revenue including the environmental tax revenue, while GI^0 is the total government revenue in the base case (i.e., before the introduction of the environment tax). Moreover, as government revenue is maintained constant, Equation 31 that represents government savings is replaced by the following equation:

$$(58) \quad SAVG = GI^0 - \sum_i CG_i .gp_i .(1 + indt_i)$$

(ii) *Recycling of tax revenue to finance cuts in existing labour tax rate*: When the tax revenue is used to finance cuts in existing labour tax rates, τL is replaced by τLNEW, which is given by:

$$(59) \quad \tau^{LNEW} = \tau^L - \tau^R$$

where

$$(60) \quad \tau^R = \frac{REVGAP}{\sum_j L_j .wr}$$

The government saving is calculated by using Equation 58 instead of Equation 31.

(iii) *Recycling of tax revenue to finance cuts in existing indirect taxes on non-energy goods and services.* When the tax revenue is recycled to finance cuts in existing indirect tax rates of on non-energy goods and services, the new indirect tax is calculated as follows:

(61) $$indt_f^{NEW} = indt_f + envt_f$$

with f = coal, oil and gas

(62) $$indt_k^{NEW} = indt_k - \omega$$

(63) $$indt_{EL}^{NEW} = indt_{EL}$$

where $\omega = \dfrac{REVGAP}{\sum_k G_k . gp_k}$ and $indt_{EL}$ is the indirect tax rate on electricity.

The government saving is calculated again by using Equation 58.

3. DATA AND PARAMETERS

A social accounting matrix (SAM) of Thailand for year 1990 constructed by Timilsina and Shrestha (2002) was used for this study. The SAM is based on the Input-Output (I/O) Tables (NESDB, 1993) and National Accounts of Thailand (NESDB, 1991). The detailed information in relation to the various electricity generating industries are presented in Appendix A.

The main parameters used in the model include price elasticity of exports (η) and elasticities of substitution between (i) the primary factor composite and the aggregate intermediate input (σ^{PFZ}), (ii) capital and labour (σ^{KL}), (iii) the energy aggregate and the material aggregate (σ^{EMT}), (iv) the fuel aggregate and electricity (σ^{FEL}), (v) domestically produced and imported goods (σ^{DM}) and (vi) individual fuels (σ^{FF}). The values of these parameters are based on existing studies and presented in Table 1.

Elasticities of substitution between electricity generated from different technologies are presented in Table 2.

Table 1: Values of elasticity parameters used in the study

Sector	Elasticity values						
	σ^{PFZ}	σ^{KL}	σ^{EMT}	σ^{FEL}	σ^{FF}	σ^{DM}	η
Agriculture	0.3	0.6	0.25	0.60	2.0	0.6	2
Fuelwood	0.2	0.6	0.25	0.60	2.0	0.6	1
Construction	0.3	0.5	0.25	0.30	0.8	0.2	2
Coal	0.2	0.6	0.25	0.50	0.8	0.2	0.2
Crude oil	0.2	0.6	0.20	0.50	0.8	4.0	4
Minerals	0.2	0.6	0.25	0.60	0.8	0.6	3
Food	0.2	0.6	0.25	0.60	2.0	0.7	3
Textile	0.3	0.6	0.25	0.60	0.8	0.7	3
Pulp and paper	0.3	0.6	0.25	0.50	0.8	0.7	3
Chemicals	0.3	0.6	0.25	0.25	0.8	0.7	3
Petroleum	0.3	0.5	0.20	0.25	0.8	4.0	4
Gas	0.2	0.5	0.20	0.10	0.1	4.0	4
Non-metals	0.2	0.5	0.25	0.25	0.8	0.6	3
Metals	0.3	0.5	0.25	0.25	0.8	0.6	3
Fabricated metals	0.3	0.5	0.25	0.20	0.8	2.0	4
Electrical machinery	0.3	0.5	0.25	0.20	0.8	2.0	4
Other manufacturing	0.3	0.5	0.20	0.60	0.8	0.7	3
Electricity generation[a]	-	-	-	-	0.8	0.7	3
Commercial	0.3	0.6	0.25	0.60	2.0	2.0	3
Transport	0.3	0.6	0.25	0.25	0.8	0.3	2
Service	0.2	0.6	0.25	0.25	2.0	0.6	2
Household	-	-	0.60	0.30	0.3	-	-

[a] Electricity generation sector is divided in to seven sub sectors . Elasticity parameters for electricity sub-sectors are provided in Table 3.

Sources: Böhringer and Rutherford (1997); Jemio and Jansen (1993); Goulder (1994); Rose and Lin (1995); Welsch (1998) and Zhang (1997)

Table 2: Elasticity of substitution between electricity generated from different technologies

Description	Value
Between hydro and thermal electricity (σ^{HT})	0.4
Among electricity generated from steam turbine, combined cycle and gas turbine (CCGT) and internal combustion (IC) engine (σ^{TH})	0.5
Among electricity generated from coal-fired, oil-fired and gas-fired steam turbine technologies (σ^{ST})	0.6
Between electricity generated from oil-fired and gas-fired CCGT technologies (σ^{CG})	0.8

Sources: Welsch (1998), Naqvi (1998) and Zhang (1997).

Table 3: Elasticity of substitution in electricity sub-sectors

Electricity generation technology (or sub sector)	Elasticity values			
	σ^{KFLMEL}	σ^{KF}	σ^{LMEL}	σ^{MTEL}
Hydro	0.3	-	0.2	0.01
Coal fired steam turbine	0.3	-	0.2	0.01
Oil fired steam turbine	0.3	0.3	0.2	0.01
Gas fired steam turbine	0.3	0.6	0.2	0.01
Oil fired combined cycle/gas turbine	0.3	0.8	0.2	0.01
Gas fired combined cycle/gas turbine	0.3	0.8	0.2	0.01
Diesel fired internal combustion engine	0.3	0.8	0.2	0.01

Sources: Bohringer and Rutherford (1997); Welsch (1998), Naqvi (1998) and Zhang (1997).

The elasticities of substitution between (i) the capital factor composite and the labour-material-electricity composite (σ^{KFLMEL}), (ii) capital and fuel (σ^{KF}), labour and the material-electricity composite (σ^{LMEL}) and (iv) the aggregate material and electricity (σ^{MTEL}) are presented in Table 3. In the household sector, the elasticity of substitutions between present consumption (i.e., consumption of goods and leisure) and savings; and the consumption of goods and leisure are calibrated following Ballard et al. (1985).

4. Results from the simulations

4.1 Tax rates required for reducing CO_2 emission to the specified level

In this study we have simulated economic and environmental impacts of reducing CO_2 emissions by 10% from the base case[10] through the introduction of each of the carbon-, sulphur-, energy- and output-tax options. The rates of each of these tax instruments required for reducing CO_2 emission by 10% from the base case and their equivalent fuel and indirect tax rates were also determined from the simulation. These are presented in Tables 4(a) to 4(d).

As can be seen from the tables, the burden of sulphur tax mainly falls on coal. The equivalent fuel (or energy) tax rate of the sulphur tax on coal would be more than twice as high as that of the carbon and energy taxes for reducing the same amount of CO_2 emission. The sulphur tax would increase the after-tax price of coal by 299% to 332%, whereas carbon and energy taxes increase the coal price by 107% to 132%. This is due mainly to the low heating value and high sulphur content of coal used in Thailand.

[10] Base case refers to the situation prior to the introduction of tax instruments considered in the study.

Table 4: Carbon, output, energy and sulphur tax rates for reducing 10% CO_2 emissions from baseline under alternative revenue recycling schemes

Table 4(a) Carbon tax

	Unit	Revenue Recycling Schemes		
		Scheme 1	Scheme 2	Scheme 3
Carbon tax rate				
Carbon	US$/tC	40.00	41.87	44.57
Equivalent sales or indirect tax on fuels (in terms of physical quantity)				
Coal	US$/ton	12.01	12.57	13.38
Oil	US$/barrel	4.45	4.66	4.96
Gas	US$/'000 cu.ft	0.61	0.64	0.69
Equivalent indirect tax rates (in terms of percentage of fuel price)				
Coal	%	118	124	132
Oil	%	23	24	25
Gas	%	31	32	34

Table 4(b) Output tax rates (%)

Good/Service	Revenue Recycling Schemes		
	Scheme 1	Scheme 2	Scheme 3
Agricultural	1.8	2.0	2.3
Fuel wood	0.2	0.2	0.2
Construction	0.5	0.6	0.7
Coal	3.5	3.9	4.6
Crude oil	1.5	1.7	2.0
Minerals	2.9	3.3	3.9
Food	0.7	0.8	0.9
Textile	0.5	0.6	0.7
Pulp & Paper	0.6	0.7	0.9
Chemicals	1.3	1.5	1.8
Petroleum	3.5	4.0	4.7
Gas	7.2	8.1	9.6
Non metals	5.6	6.4	7.5
Metals	0.5	0.6	0.7
Fabricated metals	0.3	0.4	0.5
Electrical machinery	0.2	0.3	0.3
Other manufacturing goods	0.3	0.4	0.4
Electricity	51.8	58.6	69.1
Commercial	0.4	0.5	0.6
Transport	13.6	15.3	18.1
Service	0.4	0.4	0.5

Table 4(c) Energy tax

	Unit	Revenue Recycling Schemes		
		Scheme 1	Scheme 2	Scheme 3
		Energy tax rates		
GJ	US$/GJ	1.13	1.19	1.28
	Equivalent sales or indirect tax on fuels (in terms of physical quantity)			
Coal	US$/ton	12.37	13.09	14.07
Oil	US$/barrel	6.66	7.05	7.58
Gas	US$/'000 cu.ft	1.2	1.28	1.37
	Equivalent indirect tax rates (in terms of percentage of fuel price)			
Coal	%	107	114	122
Oil	%	26	28	30
Gas	%	49	52	56

Table 4(d) Sulphur tax

	Unit	Revenue Recycling Schemes		
		Scheme 1	Scheme 2	Scheme 3
		Sulphur tax rates		
SO_2	US$/t$SO_2$	671.00	701.90	746.80
	Equivalent sales or indirect tax on fuels (in terms of physical quantity)			
Coal	US$/ton	28.15	29.45	31.33
Oil	US$/barrel	3.12	3.26	3.47
Gas	US$/'000 cu.ft.	Negligible	Negligible	Negligible
	Equivalent indirect tax rates (in terms of percentage of fuel price)			
Coal	%	299	312	332
Oil	%	17	17	18
Gas	%	Negligible	Negligible	Negligible

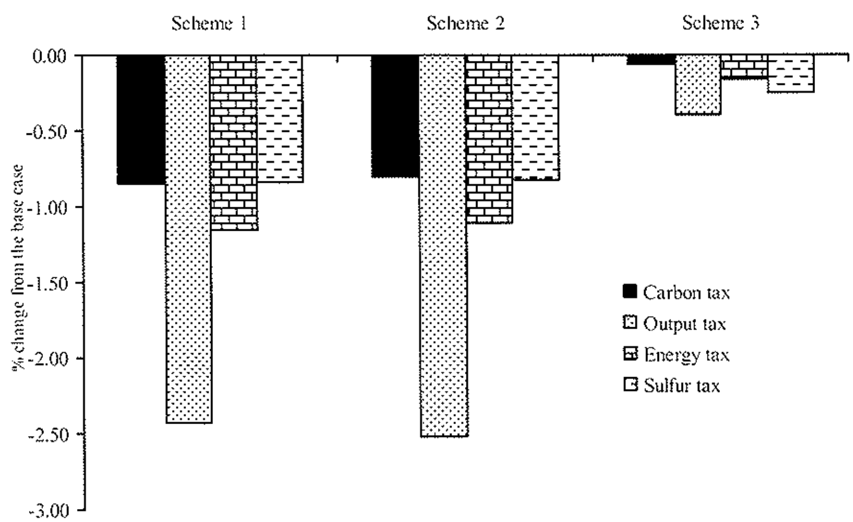
The burden of energy tax on oil is higher than that of the carbon and sulphur taxes. Note that, for each type of tax (i.e., carbon-, output-, energy- and sulphur-tax), the tax rate would vary with the revenue recycling schemes. In order to reduce the same level of CO_2 emissions, the required tax rates are found to be higher under the revenue recycling Scheme 3 (i.e., when the tax revenue is recycled to finance cuts in indirect taxes on non-energy goods) than those under the other schemes of revenue recycling. On the other hand, the required tax rate is found to be smallest under the revenue recycling Scheme 1 (i.e., when the tax revenue is recycled to household through a lump-sum transfer).

If an output tax is imposed in proportionate to the carbon intensity of a good or service (i.e., money value of total production of the good or service from a sector divided by total carbon emission released from the sector), some sectors, especially the fuel intensive ones (i.e., power and transport), would face higher tax rates than others. In order to reduce national CO_2 emission by 10% from that in the base case, the required output tax rates would be as high as 52% to 69% for electricity and 14% to 18% for transport services in Thailand.

4.2 Impacts of the alternative tax instruments on economic welfare[11]

The impacts of the alternative tax instruments on economic welfare are presented in Fig. 4. As can be seen from the figure, among the tax instruments considered, the output tax would result in the highest welfare loss under each of the revenue recycling schemes. This is because while carbon- and sulphur-taxes affect the sources of emissions (i.e., consumption of fossil fuels) directly, the output tax affects indirectly. A tax instrument that affects sources of emissions indirectly is inefficient as compared to that affects directly (Cropper and Oates, 1992; Jorgenson and Wilcoxen, 1993; Schmutzler and Goulder, 1997).

Figure 4: Welfare impacts of carbon-, output-, energy- and sulphur taxes for reducing CO_2 emission under alternative tax revenue recycling schemes



The study reveals an interesting relationship between carbon and sulphur taxes while reducing CO_2 emissions. A sulphur tax applied to reduce 10% of CO_2 emissions was found to reduce 20% of SO_2 reduction from the base case. Moreover, the sulphur tax was found slightly efficient even than the carbon tax to reduce CO_2 emission when the tax revenue is recycled to households through a lump-sum transfer (i.e., Scheme 1). A question can, however, arise: why should the sulphur tax be more efficient than the carbon tax to reduce CO_2 emission when the tax revenue is recycled through a lump-sum transfer to households? An intuitive reason behind this is that the excess burden of SO_2 tax falls mainly on coal, which has a limited use in the economy (mainly for power generation). This implies that the regressive impacts of SO_2 tax get distributed to the economy to a lower extent than the regressive impacts of CO_2 tax do.

To clarify further why SO_2 tax burden falls mainly on coal, we need to look at the quality of coal used in Thailand. Ninety eight percent of coal used in Thailand is lignite, which has

[11] Impacts on all key economic variables such as economic welfare, GDP, gross output, final and intermediate demand, imports, exports, current balance have been analyzed. However, only impact on economic welfare has been presented here for the purpose of this paper. Interested readers could request more detailed results from the authors.

high sulphur content (i.e., 5.5%) and low heat value (i.e., 11MJ/kg) (DEDP, 2000). The sulphur content of coal in Thailand is about five times as high as that of oil (i.e., the weighted average value of all petroleum products used in Thailand) while the carbon content of coal is about 1.5 times that of oil for the same amount of heat release. This clearly implies that the sulphur tax would cause a larger reduction in coal consumption than an equivalent carbon tax. Our model results show that a SO_2 tax introduced to reduce CO_2 emission by 10% from the baseline causes demand for coal to decrease by 47%, whereas a CO_2 tax for the same purpose causes demand for coal to decrease by 29%. Moreover, the SO_2 tax causes demand for natural gas to increase by 4% as natural gas, a fuel with negligible sulphur contents, becomes relatively cheaper with the sulphur tax as compared to coal and petroleum products. The CO_2 tax on the other hand causes demand for natural gas to decrease by 13%.

Note that the base year of the CGE model used for this analysis is 1990. Sulphur control technologies were not used in Thailand in 1990. If sulphur control technologies existed, the capital costs of the industries employing sulphur control technologies would have been higher than that taken in the study (i.e., in the absence of sulphur control technologies). It is also possible to model sulphur control technologies and sulphur tax under the CGE in the similar manner as Conrad and Schmidt (1998), Edwards and Hutton (1999) modeled emission abatement technologies. This could be an area of further extension of the study. This analysis has, however, an explicit objective of examining effects of carbon- and sulphur- energy- and output-taxes in reducing CO_2 emissions in an environment where no control technologies exists for reducing carbon and sulphur emissions and where electricity sector (i.e., one of the main sources of emissions) uses a low quality coal (i.e., lignite) for power generation).

The increase of natural gas demand due to sulphur tax implies that coal would be replaced with natural gas when a sulphur tax is introduced. One might wonder would the result (i.e., sulphur tax is more efficient than a carbon tax to reduce CO_2 emissions when tax revenue is recycled to households through a lump-sum transfer) holds, if the substitution possibility between fossil fuels is small in the short-run? To answer this query, we conducted a sensitivity analysis reducing elasticity of substitution between fossil fuels. If elasticities of substitution between fossil fuels are lowered by 25%, the result does not hold. The welfare loss of sulphur tax is now slightly higher than that of the carbon tax (please Table 6 in Section 5). In practice, however, there exists a high substitution possibility between coal and natural gas in Thailand. This is because coal and gas are used mainly for power generation in the country. In the absence of a sulphur tax, gas is used for mainly peaking generation and the utilization of gas fired power plants is low. If a sulphur tax is introduced, natural gas now becomes relatively cheaper than coal. Existing gas-fired power plants could now be run for longer hours than before (increased utilization factor). Hence, the finding that sulphur tax would be more efficient than carbon tax in reducing CO_2 emissions when tax revenue is recycled to households through a lump-sum transfer holds true in Thailand.

A sulphur tax can be considered an effective instrument in reducing CO_2 emissions in Thailand for two reasons. First it reduces SO_2 emission significantly higher than a carbon tax does (please see Table 5). Secondly, it could be less regressive than a carbon tax to reduce CO_2 emission. Most importantly, it could be an effective policy tool to reduce CO_2 emissions in countries like Thailand, which does not have binding obligation to reduce CO_2 emission but has been seriously affected by SO_2 emission. In such situation, SO_2 tax could be a policy choice as it reduces the local air pollution (e.g., SO_2) and also reduces CO_2 emission at almost the same level an equivalent carbon tax does.

The efficiency of a tax instrument is significantly influenced by the scheme of recycling tax revenue. When the revenues are recycled to finance cuts in either labour tax rate (Scheme 2) or indirect tax rates of non-energy goods (Scheme 3), the carbon tax is found to be the most efficient instrument for reducing CO_2 emission to the specified level. The sulphur tax is found to be more costly than not only the carbon tax but also the energy tax when the tax revenues are recycled to finance cuts in indirect tax rates of non-energy goods.

The reason for this is as follows: when the tax revenues are recycled to households in a lump-sum manner there would be only the tax-interaction effect, but not the revenue recycling effect[12].

On the other hand, the revenue recycling would have a significant effect on economic welfare when the tax revenues are recycled to finance cuts in either the labour tax rate or indirect tax rates of non-energy goods (Schemes 2 and 3)[13]. Note also that the tax revenue from the sulphur tax would be smaller than that from the carbon tax as the former affects only coal and a few petroleum products (e.g., diesel and fuel oil), whereas the latter affects all types of fossil fuels (i.e., coal, gas and oil). Since, carbon tax revenue is higher than the sulphur tax revenue for reducing the same level of CO_2 emission, the revenue recycling effect of the carbon tax on welfare would be higher than that of the sulphur tax. Hence, the carbon tax would cause a smaller welfare loss than the sulphur tax to achieve a particular level of CO_2 emission reduction when the tax revenues are recycled to finance cuts in either labour tax rate or indirect tax rates of non-energy goods. Although tax revenues under the output tax would be 2 to 3 times higher than that under the carbon- and sulphur-taxes, the revenue recycling effect would not be enough to significantly offset the tax interaction effects in the case of the output tax. As a result, there would be higher welfare loss due to the output tax.

Although the output tax is inefficient as compared to carbon-, sulphur- and energy- taxes to reduce CO_2 emissions, this type of tax instrument could be useful to penalize production of carbon intensive goods from industrialized countries not ratifying the Kyoto Protocol (Goh, 2004). For example, output tax imposed on U.S. and Australian goods by European countries, Japan and Canada could help reduce CO_2 emissions to some extent.

Note that the energy tax would result in a higher welfare cost than the carbon- and sulphur-taxes under each of the revenue recycling schemes, except when the tax revenues are recycled to finance cuts in indirect tax rates of non-energy goods (Scheme 3). This is because, for a particular level of CO_2 emission reduction, there would a proportionately higher rise in prices of relatively low carbon content fuels (i.e., oil and gas) under an energy tax than that under the carbon- and sulphur-taxes. Consequently, the energy tax would cause more economic distortions than the carbon and sulphur taxes for reducing the same level of CO_2 emission. Similar findings are also reported by some existing studies [See e.g., Jorgenson and Wilcoxen (1993) and Goulder (1994)]. However, it is interesting to note here that, in order to reduce the same level of CO_2 emission, there would be a smaller welfare loss under the energy tax than that under the sulphur tax when tax revenue is used to finance indirect tax rates of non-energy goods. This is because the revenue recycling effect of the energy tax on welfare would be higher than that of the sulphur tax when the tax revenues are recycled to finance

[12] According to Parry et al. (1999), when an environmental tax is introduced in a system where distortionary taxes are already present (i.e., the second best setting), it would further increase the tax distortions thereby producing a negative welfare impact; the effect is termed as the tax interaction effect. If the revenue generated from the new tax is recycled to finance cuts in pre-existing distortionary tax rates, it would cause positive welfare impacts; this effect is termed as revenue-recycling effect.

[13] This is why welfare loss is lower under the revenue recycling Schemes 2 and 3 than that under Scheme 1.

cuts in indirect taxes on non-energy goods.

4.3 Impacts on SO_2 and NO_x emissions

The impacts of different tax instruments on SO_2 and NO_x emissions under alternative revenue recycling schemes are presented in Table 5. As can be seen from the table, there are two interesting findings. First, different tax instruments for reducing the same level of CO_2 emission would have significantly different impacts on SO_2 and NO_x emissions. Secondly, for a given tax instrument, environmental impacts (i.e., impacts on SO_2 and NO_x) do not vary significantly across alternative revenue recycling schemes.

Table 5: Impacts of environmental taxes on SO_2 and NO_x emissions under alternative revenue recycling schemes (% change from the base case)

	Scheme 1	Scheme 2	Scheme 3
	SO_2 Emission		
Carbon tax	-13.42	-13.48	-13.79
Output tax	-11.50	-11.56	-12.17
Energy tax	-12.14	-12.17	-12.48
Sulphur tax	-20.20	-20.43	-20.86
	NO_x Emission		
Carbon tax	-10.06	-10.07	-10.01
Output tax	-8.90	-8.79	-8.48
Energy tax	-9.80	-9.80	-9.71
Sulphur tax	-10.39	-10.43	-10.42

The output tax aiming to reduce CO_2 emission by 10% would reduce SO_2 and NO_x emissions by about 12% and 9% respectively. On the other hand, the sulphur tax introduced for the same purpose (i.e., to reduce CO_2 emission by 10%) would reduce SO_2 and NO_x emissions by about 21% and 10% respectively. In terms of environmental impacts, the sulphur tax would be the best tax instrument in Thailand, as it would cause higher SO_2 and NO_x emission reductions than other tax instruments under each of the revenue-recycling scheme considered.

For a given tax instrument, percentage reductions in emissions (i.e., SO_2 and NO_x) are not found varying significantly across the revenue recycling schemes. For example, the energy tax would reduce SO_2 emission by 12.14% when tax revenue is recycled to households through a lump-sum transfer. The corresponding reductions would be 12.48% if revenue is recycled to finance cuts in existing indirect tax rates of non-energy goods.

5. Sensitivity analysis

Since the difference in percentage welfare impacts between carbon and sulphur tax cases is very small (i.e., 0.01%), particularly when tax revenue is recycled to households as a lump-sum transfer and when the tax revenue is used to finance cuts in labour tax rates, sensitivity analysis is necessary. As there are more than 180 elasticity parameters used in the study, the number of possible sensitivity analyses could be too large. Hence, only selected parameters were considered for sensitivity analysis.

In the nested structure of production or household utility function, the elasticities at the higher tiers may have larger effects than that at lower tires. Therefore, the sensitivity analyses are conducted on the elasticities of substitution at the highest tier of the production and the household sectors (i.e., elasticities of substitution between the primary factor composite and the aggregate intermediate input, σ^{PFZ} and elasticities of substitution between the capital-fuel composite and the labour-material-electricity composite, σ^{KFLMEL}). In the sensitivity analysis, the values of σ^{PFZ} and σ^{KFLMEL} are increased by 50%. The results from this sensitivity analysis show that the ranking of the tax instruments in terms of their welfare effects would not alter (please see Table 6).

Table 6: Results of sensitivity analyses (% change in economic welfare from the base case)

	Carbon tax	Sulphur tax	Energy tax	Output tax
50% increase in elasticity of substitutions at the highest level of nested structure (i.e., σ^{PFZ} and σ^{KFLMEL} are increased by 50%)				
Scheme 1	-1.41	-1.35	-1.83	-3.63
Scheme 2	-1.27	-1.28	-1.67	-3.48
Scheme 3	-0.09	-0.28	-0.22	-0.46
100% increase in all elasticities of energy substitutions (i.e., σ^{FEL}, σ^{FF}, σ^{HT}, σ^{TH}, σ^{ST}, and σ^{CG} are increased by 100%)				
Scheme 1	-0.59	-0.56	-1.00	-2.69
Scheme 2	-0.54	-0.55	-0.97	-2.63
Scheme 3	-0.04	-0.19	-0.14	-0.62
25% decrease in all elasticities of energy substitutions (i.e., σ^{FEL}, σ^{FF}, σ^{HT}, σ^{TH}, σ^{ST}, and σ^{CG} are decreased by 25%)				
Scheme 1	-0.93	-0.96	-1.81	-2.41
Scheme 2	-0.89	-0.93	-1.15	-2.35
Scheme 3	-0.08	-0.28	-0.16	-0.38
100% increase in trade elasticities (i.e., σ^{DM} and η are increased by 100%)				
Scheme 1	-0.46	-0.45	-0.60	-1.30
Scheme 2	-0.43	-0.44	-0.57	-1.25
Scheme 3	-0.19	-0.26	-0.27	-0.40

Assuming that the impacts of carbon-, sulphur- and energy-tax instruments could be influenced by the elasticity of substitution between energy commodities (i.e., between fossil fuels, between electricity and fossil fuels), all the energy substitution elasticities considered in the study are increased by 100%. The energy substitution elasticities doubled here are: elasticity of substitution between electricity generated through different technologies (i.e., σ^{HT}, σ^{TH}, σ^{ST}, and σ^{CG}); elasticity of substitution between the fuel aggregate and electricity (i.e., σ^{FEL}) and elasticity of substitution of between fuel commodities (i.e., σ^{FF}). The results of this sensitivity analysis also indicate that the ranking of the tax instrument remain intact.

In the next sensitivity analysis, we decreased values of energy substitution elasticities (by σ^{HT}, σ^{TH}, σ^{ST}, σ^{CG}, σ^{FEL} and σ^{FF}) by 25%. This sensitivity analysis is particularly interesting as it could indicate whether or not superiority of sulphur tax over the carbon tax to reduce carbon emission holds. Interestingly, we found that the result does not hold, as the welfare loss of sulphur tax is higher (-0.96%) than that of carbon tax (-0.93%). This result indicates that a sulphur tax may not be efficient as compared to carbon tax to reduce CO_2 emission if the substitution possibilities between the high sulphur content fuels (e.g., coal) and low sulphur content fuel (e.g., natural gas) is small. In reality, as discussed earlier in Section 4.2, the substitution possibility between coal and natural gas is high in Thailand even in the short-run.

Finally, the trade elasticities (i.e., Armington elasticity, σ^{DM} and price elasticity of exports, η) are increased by 100%. In this sensitivity analysis too, the ranking of the tax instruments does not change (please see Table 6).

6. CONCLUSIONS AND FINAL REMARKS

This study analyzed the effectiveness of carbon-, sulphur-, energy- and output- taxes for CO_2 emission reduction under different schemes of recycling the tax revenues in the case of Thailand. A key finding of the study is that the selection between carbon- and sulphur- tax in order to reduce CO_2 emission depends on schemes for recycling tax revenues to the economy. The study shows that, in Thailand, a sulphur tax would be more effective to reduce CO_2 emission when the tax revenues are recycled to households through a lump-sum transfer for two reasons. First, the sulphur tax designed to reduce 10% of CO_2 emissions from the base case, would also result in 20% reductions of SO_2 emissions. Secondly, the sulphur tax would cause lower welfare loss than a carbon tax if there exists substitution possibility between high sulphur content fuel (coal) and negligible sulphur content fuel (e.g., natural gas) in the short run. If the tax revenue were to recycle to households through a lump sum transfer, a SO_2 tax could be a policy choice in a country like Thailand, which does not have binding obligation to reduce CO_2 emission but has been seriously affected by SO_2 emission.

Another finding of the study is that if tax revenues are recycled to finance cuts in either labour tax rate or indirect tax rates on non-energy goods, carbon tax would be more efficient than sulphur-, energy- and output-taxes for CO_2 emission reductions. The output tax is found to be the most costly (i.e., in welfare terms) among the alternative tax instruments considered here under each of the tax revenue recycling schemes although it generates two to three times higher revenue than the other tax instruments.

While the finding that the output tax is the most inefficient among the tax instruments considered could be a generic one, the result that shows a sulphur tax is more efficient than a carbon tax to reduce CO_2 emission could be case specific. This would be true in the economy, where sulphur control technologies are not in use, where low quality coal (i.e., lignite) is one of the main sources of energy supply and where possibility of substitution between high sulphur content fuel (coal) and low sulphur content fuel (natural gas) is high even in the short run.

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Appendix A: Detailed Breakdown of the Electricity Sector in the Social Accounting Matrix of Thailand (1990)
Unit: Million Thai Baht

	Hydro Electricity	Thermal electricity									Total Electricity
		Steam turbine technology				Combined cycle and gas turbine technology			ICE	Total thermal electricity	
		Coal	Oil	Gas	Total	Oil	Gas	Total	Oil		
Agriculture	0	0	0	0	0	0	0	0	0	0	0
Fuel wood	0	0	0	0	0	0	0	0	0	0	0
Construction	7	4	6	4	15	2	4	6	1	23	30
Coal	0	5,109	0	0	5,109	0	0	0	0	5,109	5,109
Crude oil	0	0	0	0	0	0	0	0	0	0	0
Minerals	0	0	0	0	0	0	0	0	0	0	0
Food	0	0	0	0	0	0	0	0	0	0	0
Textile	4	10	9	10	28	0	6	6	0	35	39
Pulp & paper	9	20	18	20	58	0	12	13	0	70	79
Chemicals	11	25	23	25	73	1	15	16	0	88	100
Petroleum	0	0	6,383	0	6,383	932	0	932	124	7,440	7,440
Gas	0	0	0	7,899	7,899	0	4,616	4,616	0	12,515	12,515
Non metals	0	0	0	0	0	0	0	0	0	0	0
Metals	0	0	0	0	0	0	0	0	0	0	0
Fabricated metals	21	46	42	46	133	1	28	29	0	162	182
Electrical machinery	32	71	64	71	205	2	43	45	0	250	282
Other Manufacturing	2	4	3	4	11	0	2	2	0	14	15
Electricity	714	1,587	1,447	1,586	4,620	40	962	1,002	5	5,626	6,341
Commercial services	204	452	412	452	1,316	11	274	285	1	1,603	1,807
Transport services	120	267	244	267	778	7	162	169	1	948	1,068
Other services	53	118	107	118	343	3	71	74	0	418	471
Total intermediate	1,177	7,712	8,758	10,501	26,971	999	6,196	7,195	134	34,300	35,477
Labour	889	1,976	1,802	1,975	5,753	49	1,198	1,248	6	7,006	7,896
Capital	12,243	3,563	4,252	3,112	10,927	1,114	2,448	0	0	15,139	27,382

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