ENVIRONMENTAL POLICY, CAPITAL FLOWS AND INTERNATIONAL TRADE

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Abstract

Because environmental regulations differ across countries, environmental protection and international trade are inextricably linked. A country adopting relatively strict environmental standards will increase the costs of its domestic firms and may harm their ability to compete with overseas rivals. This issue is particularly important in the debate over policies to reduce carbon dioxide emissions since it has become clear that developing countries will not adopt standards as strict as those being considered by developed countries. It is possible, therefore, that carbon abatement policies in developed countries might do little more than shift carbon-intensive production to developing countries, without lowering the overall level of emissions significantly. In this paper we use an econometrically-estimated intertemporal general equilibrium model of the world economy to determine whether this effect is quantitatively significant. We find that it is not: heterogeneous carbon abatement policies cause little shifting of emissions. In addition, we show that the overall effect of an emissions tax on the international competitiveness of an economy is influenced more by how revenue from the tax is used than by whether competing countries adopt similar taxes.

1 Introduction

Because environmental regulations differ across countries, environmental protection and international trade are inextricably linked. A country adopting relatively strict environmental standards will increase the costs of its domestic firms and may harm their ability to compete with overseas rivals. One effect of this may be to cause dirty industries to migrate to countries with lax environmental regulation. Kalt (1985), for example, has argued that standard trade theory predicts that countries with low environmental standards will have a comparative advantage in production of dirty goods and so might be expected to produce relatively more of the world's most polluting products.

More recently this view has become known as the "Pollution Havens" hypothesis in recognition of the possibility that developing countries might deliberately adopt low environmental standards in order to attract foreign investment. A large literature has developed on the link between environmental regulations and firm location, and has been surveyed by Levinson (1994). To date, most evidence seems to suggest that individual firms are not very likely to relocate in order to avoid regulations because other aspects of their location decision, such as labor costs, tax rates and infrastructure are far more important.

It remains possible, however, that even if individual firms do not relocate to lightly regulated areas quickly, whole industries may move over longer periods of time. This question has been particularly important in the debate over policies to control global warming. Schelling (1992) has argued that developed and developing countries differ in their incentives to control greenhouse gas emissions (carbon dioxide, methane and chlorofluorocarbons, among others) and are unlikely to agree on a single international standard. Furthermore, Hoel (1991) has shown that a partial standard, adopted by developed but not developing countries, could actually raise world emissions by shifting production to countries with less efficient energy sectors. Felder and Rutherford (1992) have also suggested that a geographically-limited greenhouse gas policy could be vitiated by changes in trade flows. If this hypothesis is correct it implies that a limited agreement could be worse than useless: it would impose substantial costs on developed countries but achieve little or nothing in the way of emissions reductions. In the remainder of this paper we will refer to this as the "trade redirection hypothesis".

In this paper we subject the trade redirection hypothesis to an empirical test. Using a general equilibrium model of the world economy we calculate the effect of a unilateral U.S. carbon tax on trade patterns and world carbon dioxide emissions. Our approach improves on earlier studies by incorporating several key theoretical and empirical features into a single integrated model . First, we disaggregate the world economy into the eight geographic regions shown in Table 1. Other carbon tax studies have often used single region models. These include detailed models of individual countries such as Jorgenson and Wilcoxen (1991a,b) and Goulder (1991), and also aggregated world models such as Peck and Teisberg (1990). By construction, single region models are unsuitable for analysis of trade flows.

Table 1: List of Regions
United States
Japan
China
Australia
Rest of the OECD (ROECD)
Less developed countries (LDC)
Eastern Europe and the former USSR (EEB)
Oil exporting developing countries (OPEC)

Second, we disaggregate production in each region into the twelve sectors listed in Table 2. This allows us to capture the fact that carbon emissions originate in a narrow segment of the economy. Other models have multiple regions but had no industrial disaggregation; prominent examples are Edmonds and Reilly (1983), Barnes, Edmonds and Reilly (1992), Cline (1989), and Manne and Richels (1990,1992). These models are also unsuitable, by construction, for international trade analysis.

Table 2: Industries Within Each Region
Electric Utilities
Gas Utilities
Petroleum Refining
Coal Mining
Crude Oil and Gas Extraction
Other Mining
Agriculture, Fishing and Hunting
Forestry and Wood Products
Durable Manufacturing
Non-Durable Manufacturing
Transportation
Services

Third, our model includes an integrated treatment of the current and capital accounts. Specifically, we require that any current account deficit be matched by a corresponding capital account surplus. Accumulations of foreign debt must be repaid or serviced indefinitely. The link between the trade accounts also works in the opposite direction: changes in international rates of return can lead to sharp changes in capital flows and consequent changes in exchange rates and current accounts. In particular, a shock reducing the rate of return in one country will lead to capital outflow, depreciation of the exchange rate, and will force the country's current account toward surplus. One effect of a unilateral carbon tax would be to lower the domestic rate of return, so it is essential to model international capital flows in order to understand the effects of such a tax. Although this may seem like an elementary requirement for modeling international trade, ours is the only multiregion, multisector general equilibrium model with this feature. Other models with regional and industrial detail used to examine the effects of carbon taxes include Whalley and Wigle (1991), Rutherford (1992), Felder and Rutherford (1992), Rutherford and Manne (1994), and Burniaux, Martin, Nicholetti and Martins (1991a,b). None of these has a fully integrated treatment of international capital flows.

Contrary to the theoretical concerns raised by Hoel (1991) and others we find that a unilateral U.S. carbon tax would cause little trade redirection in either the short or long run. Most carbon dioxide is produced by electric power plants and local automobile transportation, both of which are largely non-traded for the United States. We find, however, that the manner in which revenue from the tax is used will have a substantial effect on the economy. In the remainder of the paper we present a summary of the model and discuss our results in more detail. We conclude by drawing some general inferences about environmental regulation and trade.

2 Modeling Individual Regions

At the most abstract level the model consists of a set of eight general equilibrium models, one for each region, linked by international flows of goods and assets.[2] We assume the regions each consist of a representative household, a government sector, a financial sector, the twelve industries shown in Table 2, and a sector producing capital goods. Although the regions are similar in structure (that is, they consist of similar agents solving similar problems), they differ in endowments, behavioral

[2] Models seem to need names so we've called ours GCUBED, short for "Global General Equilibrium Growth" model.

parameters and government policy variables.[3] In the remainder of this section we present the key features of the regional models.[4] To keep the notation from becoming cumbersome, we will generally not subscript variables by country. The complete model, however, consists of eight regional modules linked by trade and asset flows.

Producer Behavior

Within a region, each producing sector is represented by a single firm which chooses it inputs and its level of investment in order to maximize its stock market value subject to a multiple-input production function and a vector of prices it takes to be exogenous. We assume that output can be represented by a constant elasticity of substitution (CES) function of inputs of capital (K), labor (L), energy (E) and materials (M). Omitting industry and country subscripts, the production function has the following form:

$$Q = A_O \left(\sum_{j=K,L,E,M} \gamma_j^{1/\sigma_O} X_j^{(\sigma_O - 1)/\sigma_O} \right)^{\frac{\sigma_O}{(\sigma_O - 1)}} \tag{1}$$

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[3] This is enough to allow the regions to be quite different from one another. For example, even though all of the regions consist of the twelve industries in Table 2 we do not impose any requirement that the output of a particular industry in one country be identical to that of another country. The industries are themselves aggregates of smaller sectors and the aggregation weights can be very different across countries: the output of the durable goods sector in Japan will not be identical to that of the United States. The fact that these goods are not identical is reflected in the assumption (discussed further below) that foreign and domestic goods are generally imperfect substitutes.

[4] A more complete description of the model is contained in McKibbin and Wilcoxen (1995). This and other related papers are available from the Brookings Institution via the Internet. The Brookings web site is http://www.brook.edu and papers related to this model can be found under the heading for the Economics Studies Program.

where Q is the industry's output, X_j is the quantity of input j, and A_O, γ_j and σ_O are estimated parameters which vary across industries. In addition, the A_O and γ parameters vary across countries. Without loss of generality, we constrain the γ's to sum to one.

Energy and materials, in turn, are CES aggregates of inputs of intermediate goods. The form of the function is the same as for the output tier, but the inputs and estimated parameters are different. For energy:

$$X_E = A_E \left(\sum_{j=1}^{5} \gamma_j^{1/\sigma_E} X_j^{(\sigma_E - 1)/\sigma_E} \right)^{\frac{\sigma_E}{(\sigma_E - 1)}} \qquad (2)$$

where X_E is the industry's input of energy, X_j is the quantity of input j, and A_E, γ_j and σ_E are estimated parameters which vary across industries. As before, A_E and the γ parameters also vary across countries. The energy inputs are purchased from the first five industries in Table 2. The materials aggregation is defined in a similar manner from inputs of the remaining seven products.

We used a nested system of CES equations rather than a more flexible functional form because data limitations make even the CES model a challenge to estimate. In principle we need price and quantity data for 14 inputs (twelve goods plus capital and labor) in each of 96 industries (12 industries in 8 regions). Moreover, data on intermediate inputs (which is published in the form of input-output tables) is not collected annually in any major country and is collected infrequently, if at all, in developing countries. For many of our regions we had access to only a single input-output table. There is simply too little data for a more flexible specification to be feasible.

In fact, the sparsity of input-output data requires us to restrict the model further by imposing the assumption that the substitution elasticities for each industry (σ_o σ_e, and σ_m) be identical across countries (although they may differ across industries). In other words, we assume that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located. This is consistent with the econometric evidence of Kim and Lau in a number of papers (see for example Kim and Lau (1994)).

Although the substitution elasticities are identical across countries, the overall production models are not identical because we obtain the other production parameters (the γ's above) from the latest available input-output data for each country or region.[5] Thus, the durable goods sectors in the United States and Japan, for example, have identical substitution elasticities but different sets of γ parameters. The consequence of this is that the cost shares of inputs to a given industry are based on data for the country in which the industry operates, but the industry's response to price changes is identical across countries.

In effect, we are assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This is intermediate between one extreme of assuming that the regions share common technologies and the other extreme of allowing the technologies to differ across regions in arbitrary ways. The regions also differ in their endowments of primary factors, their government policies, and patterns of final demands, so although they some common parameters they are not simple replicas of one another.

To estimate the elasticities we constructed time-series data on prices, industry inputs, outputs and value-added for the country for which we were able to obtain the longest series of input-output

[5] Input-output tables were not available for the regions in the model larger than individual countries. The γ parameters for those regions were based on data for the United States.

tables: the United States. The following is a sketch of the approach we followed; complete details are contained in McKibbin and Wilcoxen (1995).

We began with the benchmark input-output transactions tables produced by the Bureau of Economic Analysis (BEA) for years 1958, 1963, 1967, 1972, 1977 and 1982.[6] The conventions used by the BEA have changed over time, so the raw tables are not completely comparable. We transformed the tables to make them consistent and aggregated them to twelve sectors. We then shifted consumer durables out of final consumption and into fixed investment.[7] We also increased the capital services element of final consumption to account for imputed service flows from durables and owner-occupied housing. Finally, we used a data set constructed by Dale Jorgenson and his colleagues to decompose the value added rows of the tables,[8] and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices.

Table 3 presents estimates of the substitution elasticities for each industry; standard errors are shown in parentheses.[9] A number of the estimates had the wrong sign or could not be estimated (the estimation procedure failed to converge). In such cases we examined the data and imposed elasticities that seemed appropriate; these values are shown in the table without standard errors. For

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[6] A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes. Subsequent to our estimation work a 1987 table has become available.

[7] The National Income and Product Accounts (and the benchmark input-output tables as well) treat purchases of consumer durables as consumption rather than investment.

[8] This data set is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were Lau Christiansen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of data is the Fourteen Components of Income Tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

[9] The parameters were estimated using systems of factor demand equations derived from the KLEM portion of the production function and the dual versions of the energy and materials tiers.

most of the imposed parameters, the data suggest complementarities among inputs, which is incompatible with the CES specification. If more data were available, it would be worthwhile to use a more flexible functional form.

Table 3: Elasticity Estimates with Standard Errors

Sec	Energy Node	Materials Node	KLEM Node
1	0.2000	1.0000	0.7634 (0.0765)
2	0.9325 (0.3473)	0.2000	0.8096 (0.0393)
3	0.2000	0.2000	0.5426 (0.0392)
4	0.1594 (0.1208)	0.5294 (0.0187)	1.7030 (0.0380)
5	0.1372 (0.0339)	0.2000	0.4934 (0.0310)
6	1.1474 (0.1355)	2.7654 (0.0278)	1.0014 (0.3146)
7	0.6277 (0.0510)	1.7323 (0.1052)	1.2830 (0.0469)
8	0.9385 (0.1380)	0.1757 (0.0000)	0.9349 (0.0802)
9	0.8045 (0.0582)	0.2000	0.4104 (0.0193)
10	1.0000	0.0573 (0.0000)	1.0044 (0.0117)
11	0.2000	0.2000	0.5368 (0.0700)
12	0.3211 (0.0449)	3.0056 (0.0728)	0.2556 (0.0272)

Maximizing the firm's short run profit subject to its capital stock and the production functions above gives the firm's factor demand equations. At this point we add two further levels of detail: we assume that domestic and imported inputs of a given commodity are imperfect substitutes, and that imported products from different countries are imperfect substitutes for each other. As noted earlier, given the model’s level of aggregation these are more a simple acknowledgment of reality than an assumption.[10] Thus, the final decision the firm must make is the fraction of each of its inputs to buy from each region in the model (including the firm's home country). Due to data constraints we represent this decision using a Cobb-Douglas function.[11] Moreover, we assume that all agents in the economy have identical preferences over foreign and domestic varieties of each particular commodity.[12] We parameterize this decision using trade shares based on aggregations of the United Nations international trade data for 1987.[13] The result is a system of demand equations for domestic output and imports from each other region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. We assume that capital is specific to each sector, that investment is subject to adjustment costs, and that firms choose their investment paths in order to maximize their market value. In addition, each industry faces the usual constraint on its accumulation of capital:

$$\frac{dK}{dt} = J - \delta K \tag{3}$$

where J is investment in new capital and δ is the rate of depreciation. As before, all variables and parameters in this equation are implicitly subscripted by industry and country.

Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To

[10] This approach is based on the work of Armington (1969).

[11] This assumption is far from ideal and we intend to relax it in future work.

[12] Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

[13] Specifically, we aggregate up from data at the 4-digit level of the Standard International Trade Classification.

formalize this we adopt Uzawa's approach by assuming that in order to install J units of capital the firm must buy a larger quantity, I, that depends on its rate of investment (J/K) as follows:

$$I = \left(1 + \frac{\phi}{2}\frac{J}{K}\right) J \tag{4}$$

where ϕ is a non-negative parameter and the factor of two is included purely for algebraic convenience. The difference between J and I may be interpreted many ways; we will view it as installation services provided by the capital vendor.

Setting up and solving the firm's investment problem yields the following expression for investment in terms of parameters, taxes, the current capital stock, and marginal q (the ratio of the marginal value of a unit of capital to its purchase price):

$$J = \frac{1}{\phi}\left(\frac{q}{(1-\tau_2)(1-\tau_4)} - 1\right) K \tag{5}$$

In this expression τ_2 is the corporate tax rate and τ_4 is rate of the investment tax credit. Following Hayashi (1979), we extend (5) by writing J as a function not only of q, but also of the firm's current profit π:

$$J = \alpha \frac{1}{\phi}\left(\frac{q}{(1-\tau_2)(1-\tau_4)} - 1\right) K + (1-\alpha)\ \pi \tag{6}$$

This improves the empirical behavior of the specification and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings. The parameter α was taken to be 0.3 based on a range of empirical estimates reported by McKibbin and Sachs (1991).

In addition to the twelve industries discussed above, the model also includes a special sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labor and capital services as well as intermediate inputs. We represent its behavior using a nested CES production function with the same structure as that used for the other sectors, and we estimate the parameters using price and quantity data for the final demand column for investment. As before, we use U.S. data to estimate the substitution elasticities and country or region data to determine the γ parameters.

Households

Households consume goods and services in every period and also demand labor and capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor services to firms and the government, and from holding financial assets. In addition, they receive imputed income from ownership of durables and housing, and they also may receive transfers from their region's government.

Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$U(t) = \int_t^{\infty} (\ln C(s) + \ln G(s))e^{-\theta(s-t)}ds$$

where C(s) is the household's aggregate consumption of goods at time s, G(s) is government consumption, which we take to be a measure of public goods supply, and θ is the rate of time preference.[14] The household maximizes its utility subject to the constraint that the present value of consumption be equal to human wealth plus initial financial assets. Human wealth (H) is the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth (F) is the sum of real money balances, real government bonds in the hands of the public (Barro neutrality does not hold in this model because some consumers are liquidity-constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. Under this specification, the desired value of each period's consumption is equal to the product of the time preference rate and household wealth:

$$P^{c}C = \theta(F + H) \tag{8}$$

There has, however, been considerable debate about whether the actual behavior of aggregate consumption is consistent with the permanent income model.[15] Based on the evidence cited in Campbell and Mankiw (1990), we assume that only a fraction β of all consumers choose their consumption to satisfy (8) and that the remainder consume based entirely on current after-tax income. This could be interpreted in various ways, including the presence of liquidity-constrained households or households with myopic expectations. For the purposes of this paper we will not adopt any

[14] This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable. Also, since utility is additive in the logs of private and government consumption, changes in government consumption will have no effect on private consumption decisions.

[15] Some of the key papers in this debate are Hall (1978), Flavin (1981), Hayashi (1982), and Cambell and Mankiw (1990).

particular explanation and will simply take β to be an exogenous constant.[16] This produces the final consumption function shown below:

$$P^{c}C = \beta\theta(F + H) + (1 - \beta)\nu INC \tag{9}$$

where ν is the marginal propensity to consume for the households consuming out of current income. Following McKibbin and Sachs (1991) we take β to be 0.3 in all regions.[17]

Within each period, the household allocates expenditure among goods and services in order to maximize C(s), its intratemporal utility index. In this version of the model we assume that C(s) may be represented by a Cobb-Douglas function of goods and services.[18]

Finally, the supply of household capital services is determined by consumers themselves who invest in household capital. We assume households choose the level of investment to maximize the present value of future service flows (taken to be proportional to the household capital stock), and that investment in household capital is subject to adjustment costs. In other words, the household investment decision is symmetrical with that of the firms.

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[16] One side effect of this specification is that it will prevent us from using equivalent variation or other welfare measures derived from the expenditure function. Since the behavior of some of the households is implicitly inconsistent with (8), either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

[17] Our value is somewhat lower than Cambell and Mankiw's estimate of 0.5.

[18] This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant empirical evidence against this assumption and we intend to generalize it in future work.

Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among final goods, services and labor in fixed proportions, which we set to 1987 values for each region. Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales, corporate, and personal income taxes, and by issuing government debt. In addition, there can be taxes on externalities such as carbon dioxide emissions.

We assume that agents will not hold government bonds unless they expect the bonds to be serviced, and accordingly impose a transversality condition on the accumulation of public debt in each region that has the effect of causing the stock of debt at each point in time to be equal to the present value of all future budget surpluses from that time forward. This condition alone, however, is insufficient to determine the time path of future surpluses: the government could pay off the debt by briefly raising taxes a lot; it could permanently raise taxes a small amount; or it could use some other policy. We assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt. In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Thus, any increase in the debt will be matched by an equal present value increase in future budget surpluses. Other fiscal closure rules are possible such as always returning to the original ratio of government debt to GDP. These closures have interesting implications but are beyond the scope of this paper (see Bryant and Long (1994)).

Labor Market Equilibrium

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, within each region wages will be equal across sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model where nominal wages are set based on current and expected inflation and on labor demand relative to labor supply. In the long run labor supply is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labor. For a given nominal wage, the demand for labor will determine short-run unemployment.

Relative to other general equilibrium models, this specification is unusual in allowing for involuntary unemployment. We adopted this approach because we are particularly interested in the transition dynamics of the world economy. The alternative of assuming that all economies are always at full employment, which might be fine for a long-run model, is clearly inappropriate during the first few years after a shock.

Money Demand

Finally, because we our wage equation depends on the rate of expected inflation, we need to include money demand and supply in the model. We assume that money demand arises from the need to carry out transactions and takes the following form:

$$\frac{M}{P} = Yi^{\epsilon}$$

where M is money, P is the price level, Y is aggregate output, I is the interest rate and ϵ is the interest elasticity of money demand. Following McKibbin and Sachs (1991) we take ϵ to be -0.6. The supply of money is determined by the balance sheet of the central bank and is exogenous.

3 International Trade and Asset Flows

The eight regions in the model are linked by flows of goods and assets. Each region may import each of the 12 goods from potentially all of the other seven regions. In terms of the way international trade data is often expressed, our model endogenously generates a set of twelve 8x8 bilateral trade matrices, one for each good. The values in these matricies are determined by the import demands generated within each region.

Trade imbalances are financed by flows of assets between countries. We assume that asset markets are perfectly integrated across the four OECD regions and that financial capital is freely mobile.[19] Under this assumption, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

$$i_k = i_j + \frac{dE_k^j/dt}{E_k^j} \tag{11}$$

where E_k^j is the exchange rate between currencies of countries k and j. In generating the baseline of the model we allow for risk premia on the assets of alternative currencies although in counterfactual

[19] The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980). Also, this assumption should not be confused with our treatment of *physical* capital, which we assume to be specific to sectors and regions and hence completely immobile. The consequence of assuming mobile financial capital and immobile physical capital is that there can be windfall gains and losses to owners of physical capital. For example, if a shock adversely affects profits in a particular industry, the physical capital stock in that sector will initially be unaffected. Its value, however, will immediately drop by enough to bring the rate of return in that sector back to into equilibrium with that in the rest of the economy.

simulations of the model, these risk premia are assumed to be constant and unaffected by the shocks we consider.

For the four non-OECD regions we also assume that exchange rates are free to float and that financial capital is freely mobile. This may appear less plausible for developing countries than it does for the OECD since many developing countries have restrictions on short-term flows of financial capital. However, the capital flows in our model are the sum of short-term portfolio investment and foreign direct investment, and the latter is usually subject to fewer restrictions. In many countries with constraints on financial instruments there are large flows of direct foreign investment responding to changes in expected rates of return. In future work we intend to add more institutional detail to our model of financial markets in the developing regions. Finally, we also assume that OPEC chooses its foreign lending in order to maintain a desired ratio of income to wealth subject to a fixed exchange rate with the U.S. dollar.

4 Constructing the Base Case

To solve the model, we first normalize all quantity variables by the economy's endowment of effective labor units. This means that in the steady state all real variables are constant in these units although the actual levels of the variables will be growing at the underlying rate of growth of population plus productivity. Next, we must make base-case assumptions about the future path of the model's exogenous variables in each region. In all regions we assume that the rate of growth of energy efficiency is 1 percent per year, the long run real interest rate is 5 percent, tax rates are held at their 1990 levels and that fiscal spending is allocated according to 1990 shares. Table 4 summarizes assumptions that differ across regions.

Table 4: Regional Assumptions Used in Generating the Baseline

(All values are expressed as annual percentage growth rates.)

	USA	Japan	Australia	Other OECD	China	LDCs	Eastern Europe
Population	0.5	0.0	0.8	0.7	1.5	1.0	0.5
Productivity in non-energy sectors	2.0	2.5	2.2	2.3	4.0	2.5	2.0
Productivity in energy sectors	1.5	2.0	1.7	1.8	4.0	2.5	1.5

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050. This a formidable task: the endogenous variables in *each* of the sixty periods number over 6,000 and include, among other things: the equilibrium prices and quantities of each good in each region, intermediate demands for each commodity by each industry in each region, asset prices by region and sector, regional interest rates, bilateral exchange rates, incomes, investment rates and capital stocks by industry and region, international flows of goods and assets, labor demanded in each industry in each region, wage rates, current and capital account balances, final demands by consumers in all regions, and government deficits.[20] At the solution, the all budget constraints for all agents are satisfied, including both intratemporal and intertemporal constraints.

[20] Since the model is solved for a perfect-foresight equilibrium over a 60 year period, the numerical complexity of the problem is on the order of 60 times what the single-period set of variables would suggest. We use software developed by McKibbin (1992) for solving large models with rational expectations on a personal computer.

For the purposes of this paper, the most important results of the base case calculation are the future paths of carbon dioxide emissions, which are shown in Figure 1. Global emissions rise from 5,388 million metric tons of carbon in 1990 to 11,752 million tons in 2020. United States emissions over this period rise from 1339 million tons in 1990 to 1,854 million tons. Emissions growth in China and the LDCs is particularly high because of economic growth is highest in those regions. Regional shares in total emissions are shown in Table 5. These results are preliminary and should be interpreted cautiously. In future work we expect to test the sensitivity of these figures to assumptions about the projected paths of productivity, population and energy efficiency improvements..

Table 5: Share of Each Region in Global Carbon Emissions

	1990	2000	2010	2020
USA	24.9	21.1	16.7	12.7
Japan	5.9	5.1	4.2	3.5
Australia	1.4	1.4	1.3	1.1
Other OECD	19.0	17.4	15.5	13.6
China	11.3	14.5	15	16.2
LDCs	18.8	19.1	21.9	23.9
Eastern Europe and former Soviet Union (EEB)	18.7	21.4	25.5	29.0

5 Unilateral vs Multilateral Carbon Tax Policies

We now present results from two simulations designed to investigate the link between trade flows and environmental policy. The first simulation examines the effects of unilateral action by the United States intended to slow global carbon emissions. We assume the U.S. applies an unexpected, permanent tax on the use of coal and crude petroleum equal to $15 per ton of carbon contained in each fuel. The tax begins in 1990 and applies to both domestic and imported fuels. The revenue raised by the tax is used to reduce the fiscal deficit.[21] If the trade redirection hypothesis is correct, we would expect the following chain of effects in the United States: fuel prices will rise; fuel use (and hence carbon emissions) will fall; domestic producers of energy-intensive goods will become less competitive on the world market; exports of energy-intensive goods will fall; imports of energy-intensive goods will increase; and the balance of trade will move toward deficit. All this would lead to a fall in U.S. carbon emissions but a rise in emissions in other countries as energy-intensive production shifted from the U.S. overseas.

The second simulation is intended to determine the benefits of international coordination. We impose the same carbon tax as in simulation one, but in all OECD countries rather than just in the United States. The revenue from each region's tax is used to reduce that region's fiscal deficit. If the trade redirection hypothesis is correct we would expect the trade effects from the previous simulation to be attenuated since the U.S. and its major trading partners would be adopting identical policies.

Figures 2 and 3 show the macroeconomic effects of the two simulations on the United States over the next thirty years. The main result is clear: the unilateral tax is worse for the U.S. economy. Under the unilateral tax, real GDP falls by 0.24 percent at the announcement of the policy in 1990.[22] By 2005, the cyclical effects of the tax have worn off and GDP has recovered

[21] Because we force the government to be on its intertemporal budget constraint, reducing the deficit has two distinct effects: (1) it reduces current public-sector borrowing, and (2) it reduces future taxes by lowering the stock of government debt and hence reducing future interest costs. This is a key assumption and will be explored in more detail in the next section.

[22] It is important to note that these effects do not include any benefits of reduced greenhouse gas emissions. Reducing fuel use would lower emissions of conventional pollutants, in addition to

slightly to 0.14 percent below the base case. In the OECD-wide case, however, the fall in GDP is attenuated to -0.18 percent at the trough and -0.10 in the long run.

These differences in the path of GDP are reflected in the fiscal deficit. Revenue from the carbon tax reduces the deficit in both simulations since government spending is exogenous and held constant. However, the fall in GDP offsets this to some extent because tax rates are exogenous and the overall tax base erodes. The larger loss of GDP under the unilateral policy causes a larger fall in tax revenue and thus leads to a smaller improvement in the deficit.

The most conspicuous difference between the two policies can be seen in the results for the current account. Under the unilateral tax, the U.S. current account moves sharply toward surplus. This is exactly the *opposite* of what one would expect under the trade redirection hypothesis: one would expect the current account to move toward deficit as costs rise in the U.S. relative to its trading partners.

This result comes about because the unilateral carbon tax causes changes in international capital flows which overwhelm the terms of trade effect. Capital flows change for two reasons. First, the carbon tax lowers the marginal product of physical capital in the U.S. and therefore lowers the rate of return on U.S. assets.[23] By itself, this would tend to reduce capital inflows as investors shifted their financial capital toward higher-yielding foreign assets. In this simulation,

slowing global warming, but we do not capture these effects in the model.

[23] Recall that although financial capital is freely mobile, physical capital is completely immobile. Together these features mean that a shock affecting the marginal product of capital in some sector is immediately reflected in corresponding change in the asset value of the capital. For example, if the earnings in the durable goods sector in the U.S. fall because of the tax, the stock market value of the sector will drop accordingly. Thus, the rate of return on financial capital will be equated throughout the world (after accounting for expected exchange rate changes) but the marginal products of capital will generally not be equated.

however, a second effect also occurs. Using the revenue from the tax to reduce public-sector borrowing causes a sharp drop in U.S. demand for foreign financial capital (which had previously been financing part of the deficit). This works in the same direction as the marginal product effect and together the two effects lead to a substantial drop in capital inflows. This causes the U.S. dollar to depreciate, improving the U.S. trade balance. The improvement in the current account is simply a reflection of the change in the capital account. Thus, as far as the balance of payments is concerned, the macroeconomic saving and investment relationship dominates the compositional effects of the change in inputs prices. The deficit-reduction effect disappears under the OECD policy because in that case all of the OECD countries are reducing their deficits and there is much less change in relative rates of return. In both simulations the results are driven strongly by our assumption that the extra tax revenue is used for deficit reduction. We will discuss several other possibilities below.

To put this point more firmly, these results show that the trade effects of a carbon tax are overwhelmingly determined by how the revenue is used, rather than by changes in relative prices at home and overseas. In part this is simply due to the inescapable fact that the use of the revenue is very important in determining the GDP effects of the policy. In part, however, it is also due to the finding here that carbon taxes have relatively little effect on the prices of traded goods. In percentage terms a carbon tax falls most heavily on coal, which has the highest carbon content of all fossil fuels and is also the least expensive. Worldwide, most coal production is used domestically. Moreover, most of it is used to generate electricity, which is essentially not traded.[24] Thus,

[24] Substantial electricity trade occurs *within* regions, especially Europe, but little occurs *between* regions.

one of the principal effects of a carbon tax is to increase the price of electricity by a few percent. This leads to a small decline in electricity consumption and a shift away from coal-fired power plants toward natural gas. Energy costs are a very small portion of industry costs or household expenses, so there is little effect on prices or demands downstream.[25] The tax also has a small effect on transportation fuel prices. These impacts can be seen in Figures 4 through 7, which show the effects of the policies on energy sector prices, outputs, employment and capital stocks.[26] Each variable is shown as its percentage deviation from the base case. There is little difference at the industry level between the unilateral and multilateral policies.

The percentage changes in U.S. carbon emission under both taxes are shown in Figure 8. Both policies produce about a 10 percent reduction in carbon emissions in 1990. This is a short run effect and is strongly influenced by the fact that capital stocks are fixed in the short run. By 2020, after capital stocks have had time to adjust, the percentage reduction relative to the base case rises to about 18 percent. The similarity between the two sets of results shows that the unilateral tax does not cause large redirections of energy-intensive trade flows. U.S. fuel use (and hence carbon emissions) are affected far more by the direct impact of the tax than by whether or not the policy is coordinated with the United States' major trading partners. The overall GDP effect, on the other hand, depends almost entirely on what is done with the tax revenue.

[25] It is true as a general rule that energy is a small part of industry costs, but there are a few notable exceptions such as aluminum refining. These industries would be affected more strongly than the more aggregate sectors in our model, but they do not account for a very large share of total energy use.

[26] Gas utilities are omitted to save space.

6 Alternative Uses of Revenue

In the previous section we assumed that the carbon tax revenue is used to reduce the fiscal deficit. However, the revenue might be used in other ways. In this section we consider a number of alternative uses of carbon tax revenue or "revenue recycling" policies; these are listed in Table 6. In all policies except the deficit reduction case, the tax cuts or credits are designed to be deficit-neutral--that is, the carbon tax and the revenue policy together leave the deficit essentially unchanged.[27]

Table 6: Alternative Revenue Recycling Assumptions

- Deficit reduction;
- Immediate lump sum rebate to households;
- Investment tax credit to all capital except household capital;
- Reduction in the tax rate on corporate income.

The first two policies are essentially aimed at stimulating saving. The deficit reduction case is identical to that discussed previously; it leads to a sharp increase in net domestic saving. The lump sum case differs from deficit reduction because of the households who consume out of current income. As a result, it produces a smaller increase in net saving. The other two policies stimulate investment, either by lowering the cost of new capital or raising its rental value. As shown by Goulder and Eichengreen (1989), policies to stimulate savings and investment can have quite different effects in open economies.

[27] This means that the amount of revenue collected by the carbon tax is not guaranteed to equal the amount of revenue distributed by the tax cut or investment tax credit. The two will differ to the extent that the carbon tax causes a contraction in the tax base elsewhere as output falls (which would otherwise tend to worsen the deficit).

The results for real GDP under a unilateral carbon tax are shown in Figure 9. Several points are evident. First, deficit reduction or a lump sum rebate both lead to similar short and long run declines in real GDP ranging between of -0.25 to -0.12 percent relative to the base case.[28] This occurs because both policies reduce the return on U.S. capital and neither does much to compensate. Under either policy, the U.S. is a somewhat less attractive place to invest. The results for GNP (not shown) are somewhat more positive, reflecting the increased U.S. ownership of assets.

The picture is quite different under the revenue policies designed to stimulate investment. If the revenue is recycled as a cut in the corporate tax rate, the negative aggregate effects of the carbon tax are completely offset by 1994. Moreover, beyond 1994 GDP is actually higher than in the base case. Recycling the revenue as an investment tax credit is even better in terms of aggregate GDP, raising it above the base case within three years and leaving it 0.2 percent higher than the base case in the long run.[29] Both rebate schemes increase the rate of return on physical capital relative to the base case, and that leads to faster capital accumulation and higher GDP. This confirms the findings of Goulder and Eichengreen that investment policies are more effective than savings policies at stimulating GDP growth.

Figures 10 and 11 contain results for the U.S. current account and trade balance, respectively. The only improvement in the current account occurs when the revenue from the tax is used to cut the fiscal deficit. In all other cases the current account and trade balance deterio-

[28] It must be stressed that this result does *not* imply that deficit reduction per se is bad. Rather, it shows that cutting the deficit does not undo the GDP decline caused by the carbon tax.

[29] The ITC has a large effect on GDP but it would probably not be the best policy in terms of consumer welfare because it increases investment at the expense of consumption.

rate. This occurs because the effect of the carbon tax is to induce energy users to substitute away from fuels and toward capital, especially in the electric sector. Increased capital intensity raises the relative rate of return on capital, increasing interest rates (Figure 12). This, in turn, leads to increased capital inflow and appreciation of the exchange rate (Figure 13).[30] In addition, the corporate tax cut and the investment tax credit both raise the after-tax rate of return on U.S. assets, drawing in even more capital from abroad and pushing the current account further toward deficit.

At the level of individual sectors, the revenue policies are fairly similar. The most interesting differences are in energy sector capital stocks, as shown in Figures 14-17. Electricity production becomes slightly more capital-intensive under all policies, with the largest change occurring under the investment tax credit, and the second largest occurring under the corporate tax reduction. The refined petroleum sector is also interesting. Under most revenue policies, declining demand for fuels leads the industry to contract, and its capital stock to fall. Under the ITC and corporate tax policies, however, the industry's capital stock rises even while output (not shown) is falling. This occurs because the investment policies cause the industry to substitute capital for labor and other inputs. The coal and crude petroleum sectors show a similar, though less pronounced, increase in capital intensity under the ITC and corporate tax experiments.

Overall, the use of revenue from a carbon tax has a minor effect on energy sectors but can have a major impact on the output of non-energy sectors. Policies which raise production in non-

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[30] Combining the uncovered interest parity condition with rational expectations implies that the change in the initial value of the exchange rate will be equal to the sum of future changes in interest rate differentials plus the change in the equilibrium exchange rate.

energy sectors reduce the overall cost of abating carbon emissions. Even though these revenue policies have similar effects on the energy industry, they create large differences in the path of GDP.

7 Conclusion

Based on our results, we conclude that a modest unilateral carbon tax is unlikely to cause much trade redirection. We find, moreover, that coordination, or lack thereof, has little effect on domestic U.S. emissions when the U.S. imposes a carbon tax. Only a very small part of U.S. carbon-intensive production is transferred overseas when the U.S. imposes a carbon tax unilaterally. This result comes about because the most carbon-intensive activities in the economy are largely non-traded. Coordination does, however, reduce the overall GDP cost associated with any given emissions target.

We also find that how the revenue from the tax is used can have a large effect on the economy. In fact, the distortionary effects of capital taxation appear large enough that a carbon tax could actually increase GDP if the revenue were used to reduce capital taxes or to provide an investment tax credit. However, this result depends crucially on our use of an infinitely-lived representative agent to model saving behavior. The effect of this assumption is to make the long-run supply of savings very elastic near the growth-adjusted rate of time preference. Other formulations could yield smaller excess burdens for capital taxes.

Finally, our results demonstrate the importance of incorporating international capital flows in the analysis of the dynamic effects of policies that influence rates of return on capital. Changes in expected rates of return (either directly through a tax change or indirectly through endogenous changes in aggregate saving and investment), can lead to large movements of financial capital. These movement, in turn, affect exchange rates and the relative prices of traded goods. Models which include trade flows between economies but ignore flows of international financial capital cannot adequately capture the effect of tax policies on international competitiveness. Moreover, the error is not just in magnitude: in some circumstances, even the sign of the effect will be wrong in a model without capital flows. Capital flows play a central role in determining the effects of environmental policies on international trade and cannot be ignored.

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Figure 1: Baseline Carbon Emissions 1990 to 2020

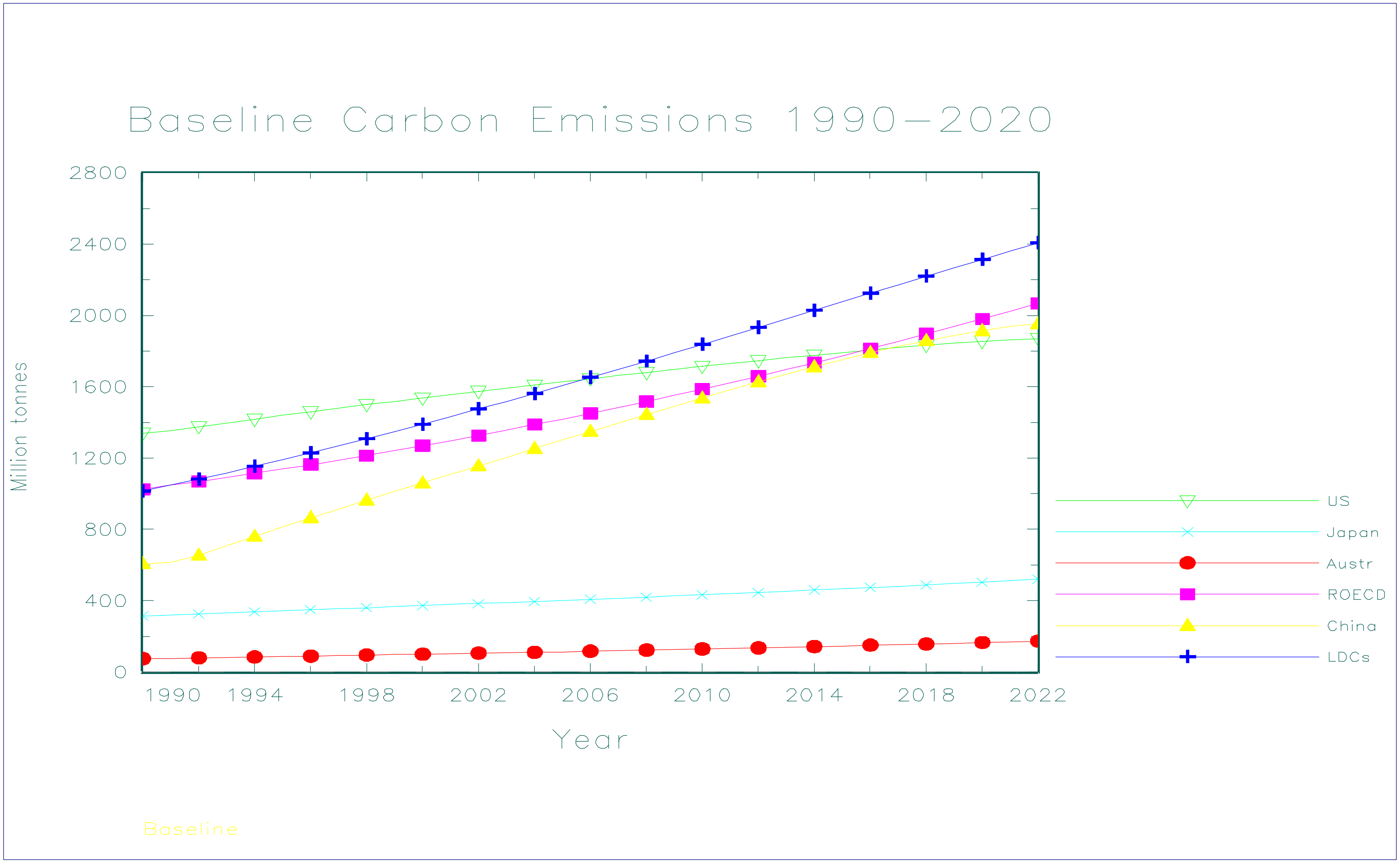

Figure 2: Macroeconomic Effects of Unilateral versus Multilateral Carbon Taxes

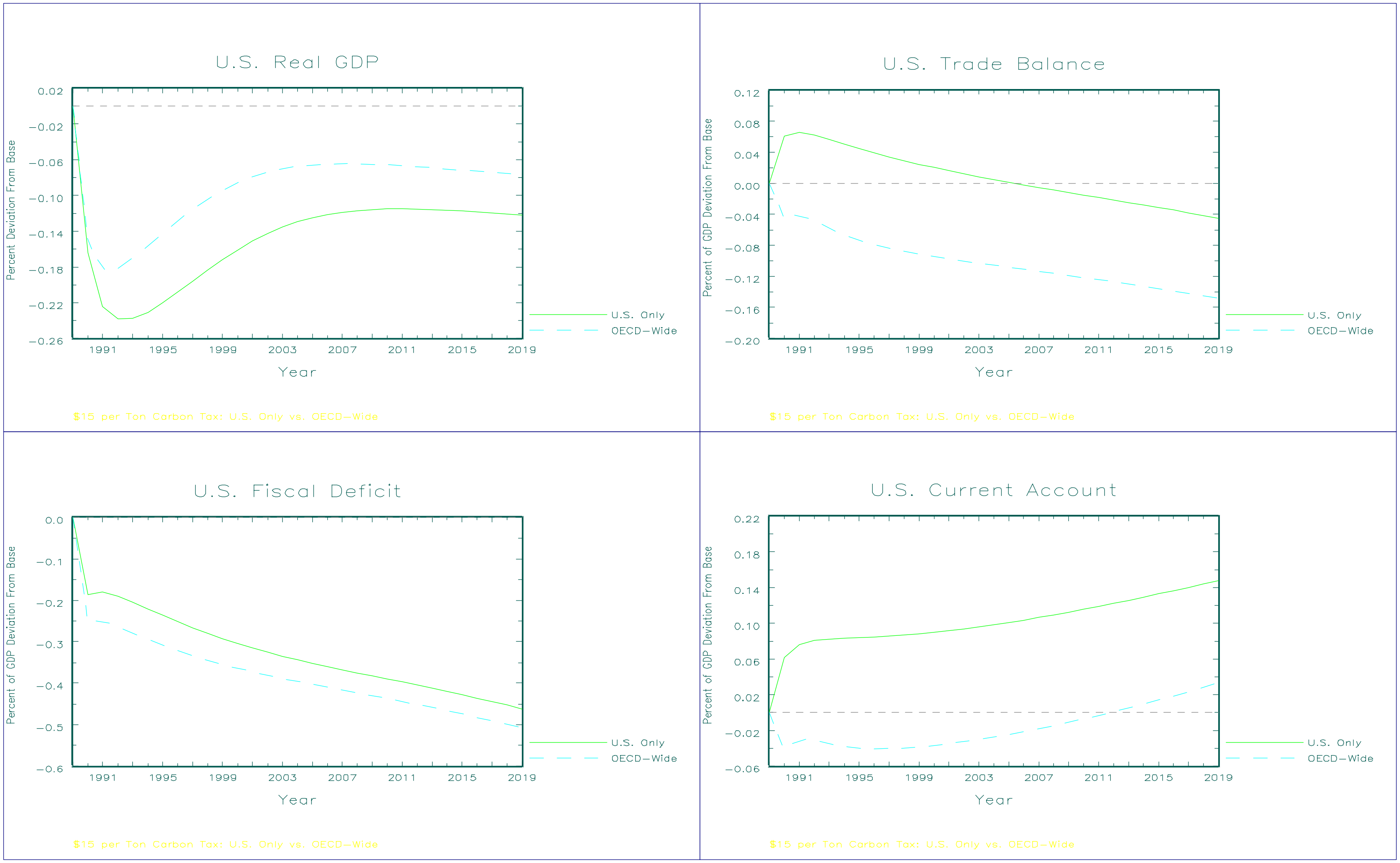

Figure 3: Financial Effects of Unilateral versus Multilateral Carbon Taxes

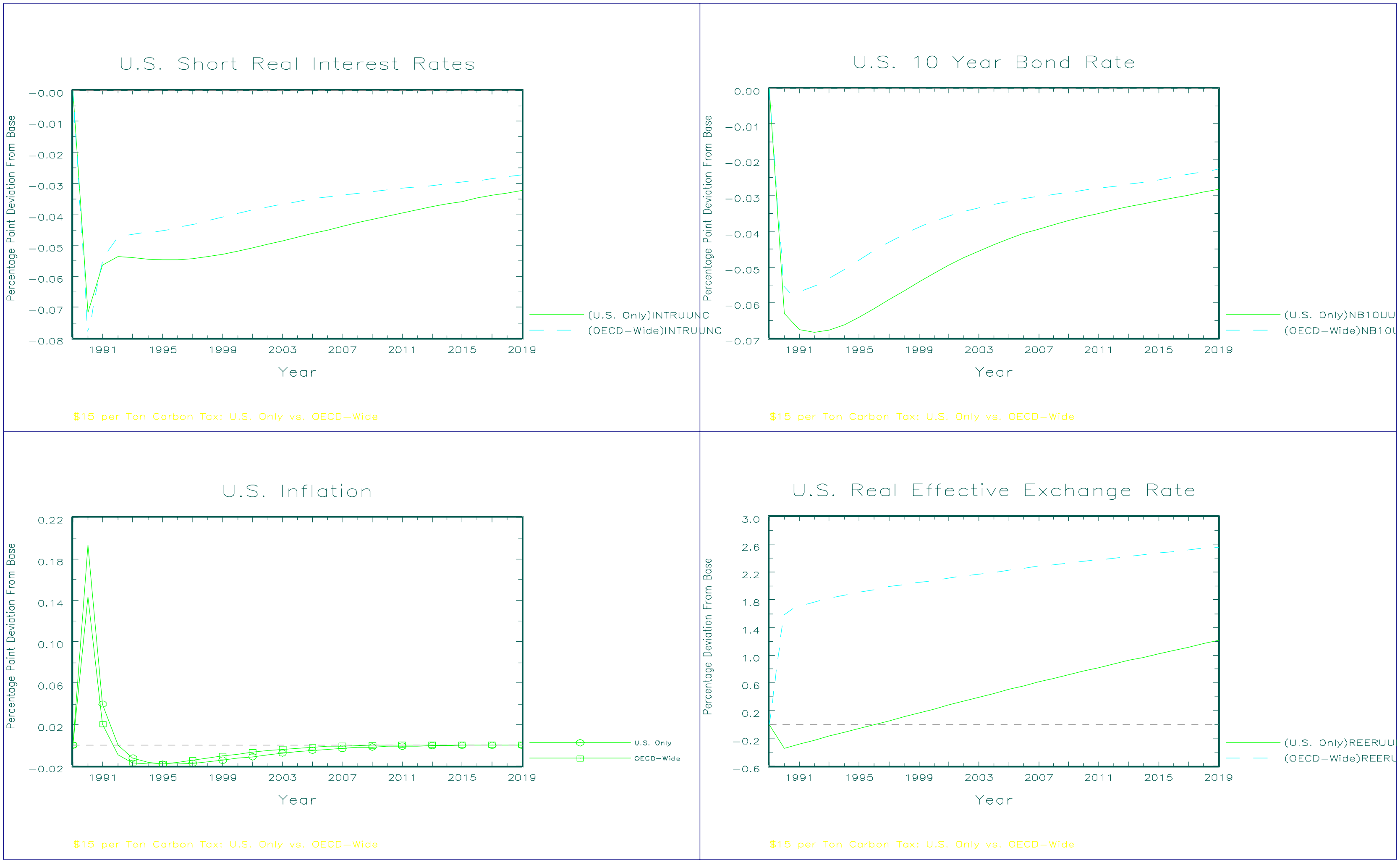

Figure 4: Energy Prices: Unilateral versus Multilateral Carbon Taxes

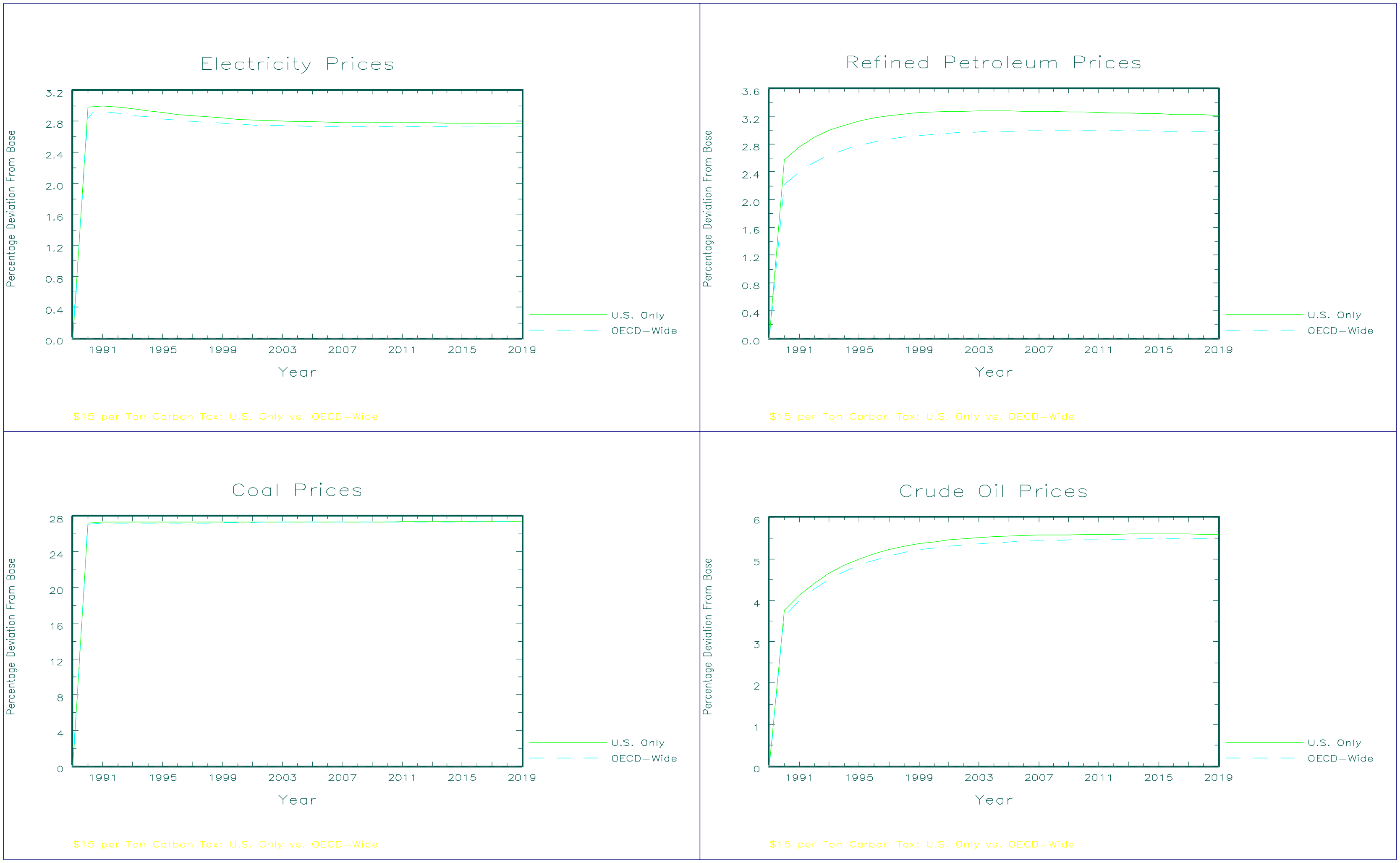

Figure 5: Output of Energy Sectors: Unilateral versus Multilateral Carbon Taxes

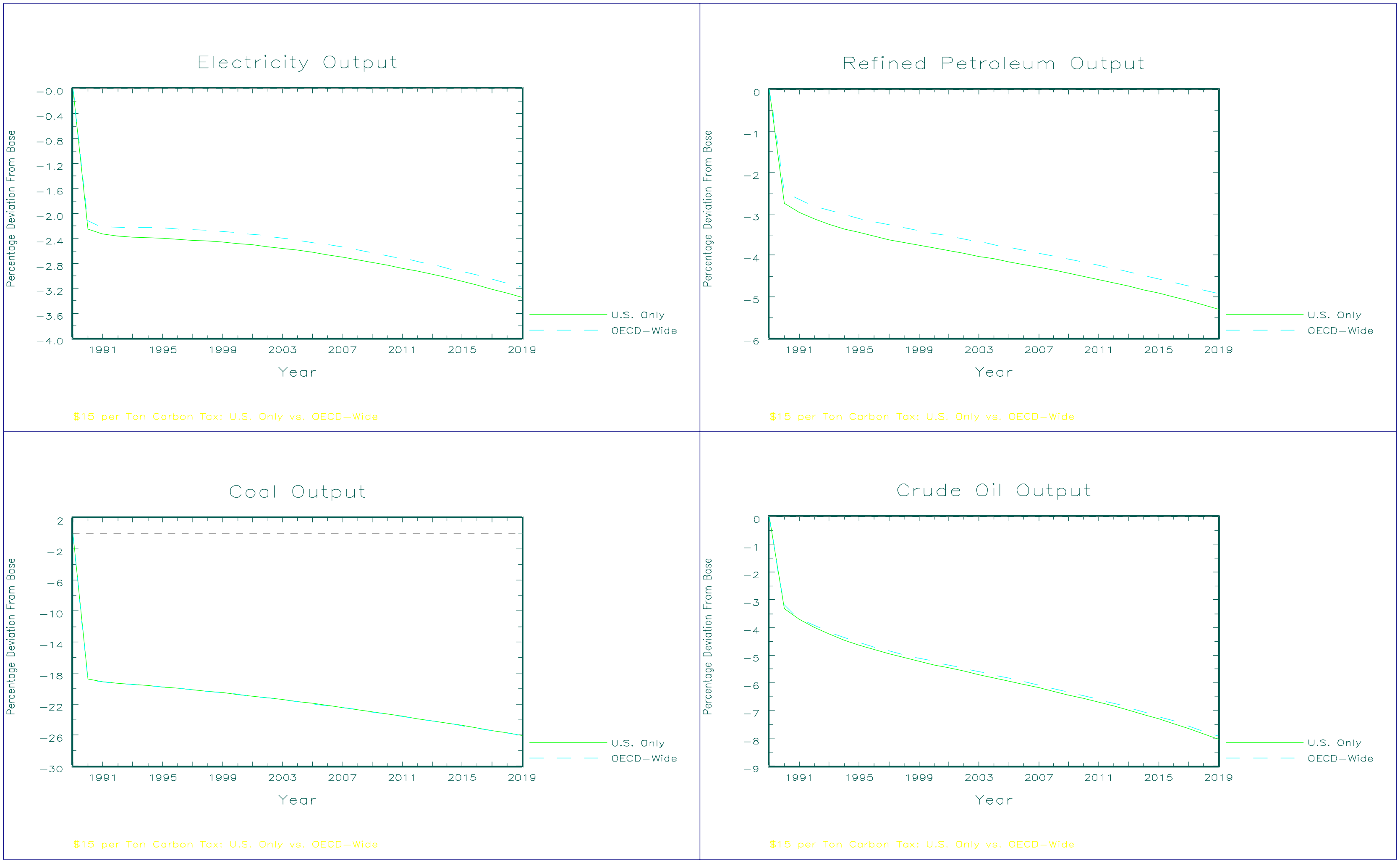

Figure 6: Employment in Energy Sectors: Unilateral versus Multilateral Carbon Taxes

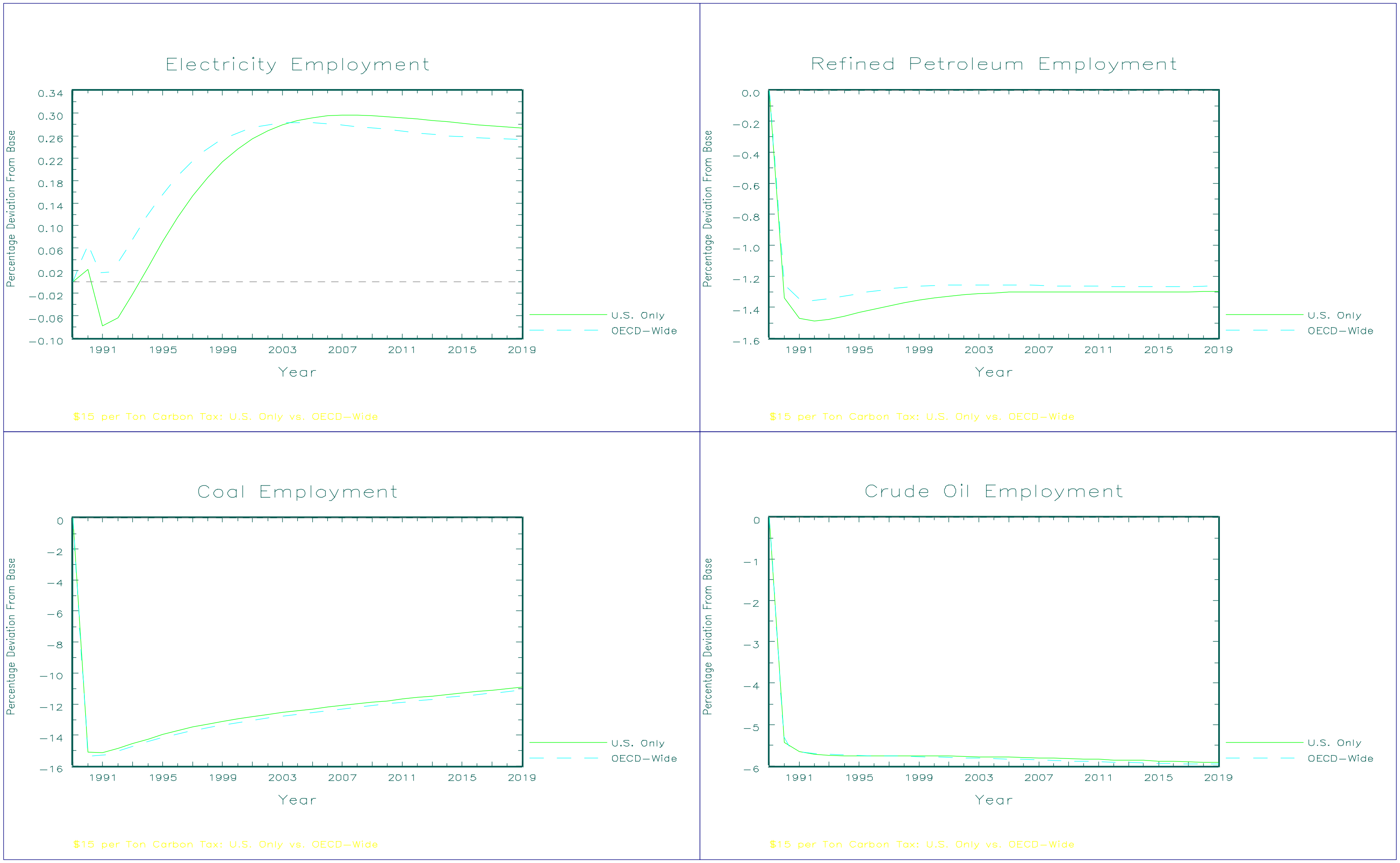

Figure 7: Capital Stock in Energy Sectors: Unilateral versus Multilateral Carbon Taxes

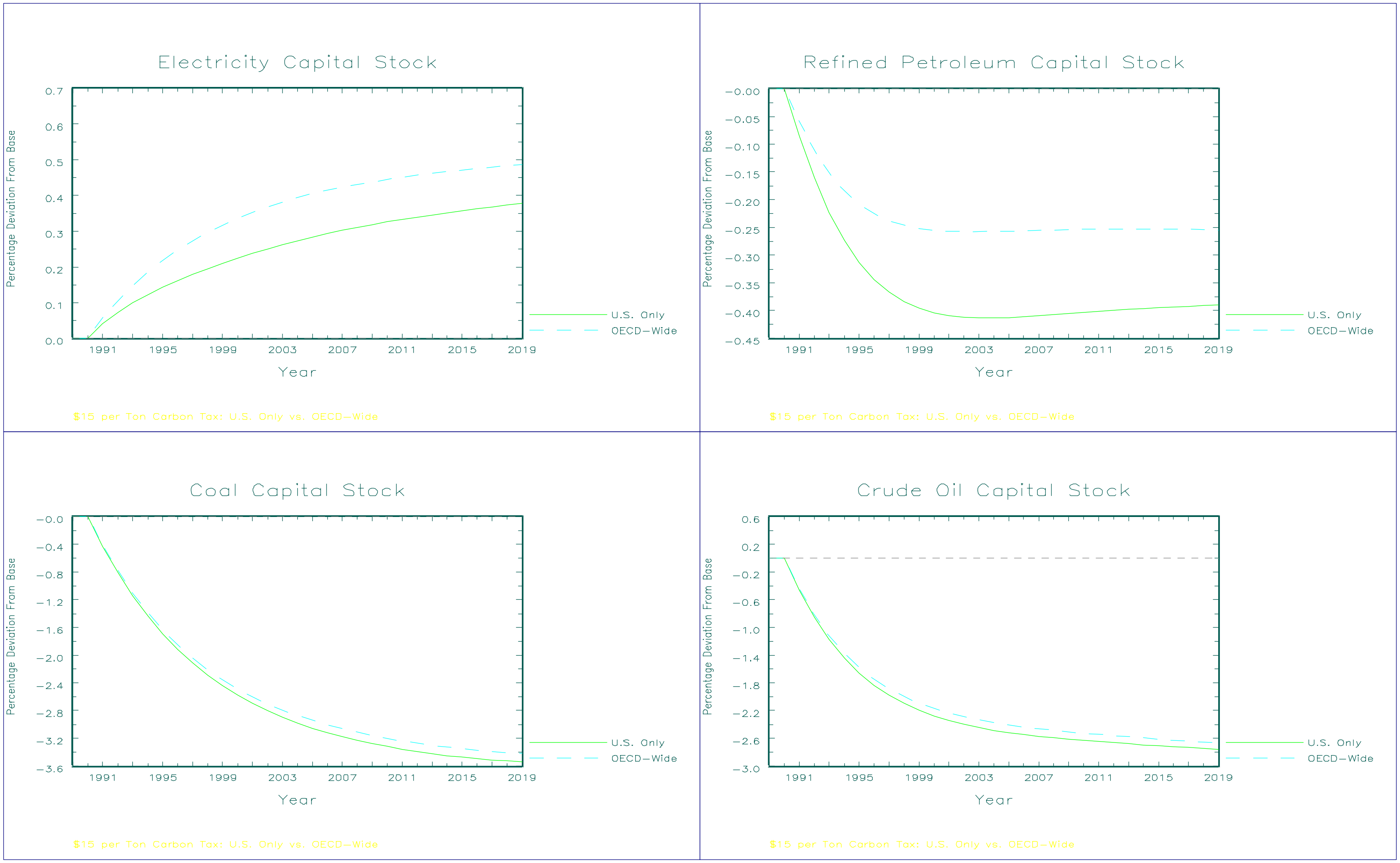

Figure 8: Consequences for Real GDP of a Carbon Tax Under Alternative Revenue Recycling Assumptions

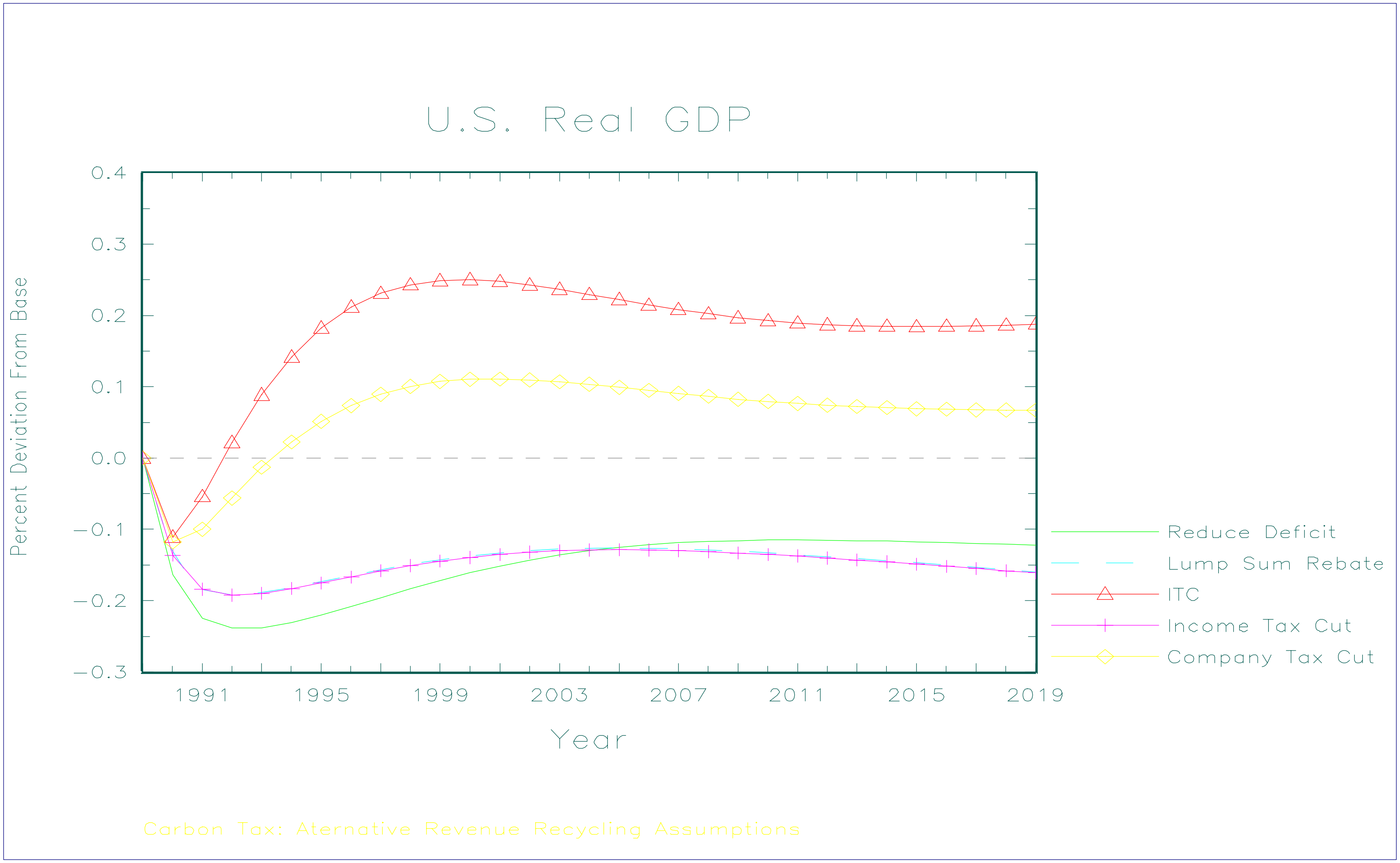

Figure 9: Consequences for the Current Account of a Carbon Tax Under Alternative Revenue Recycling Assumptions

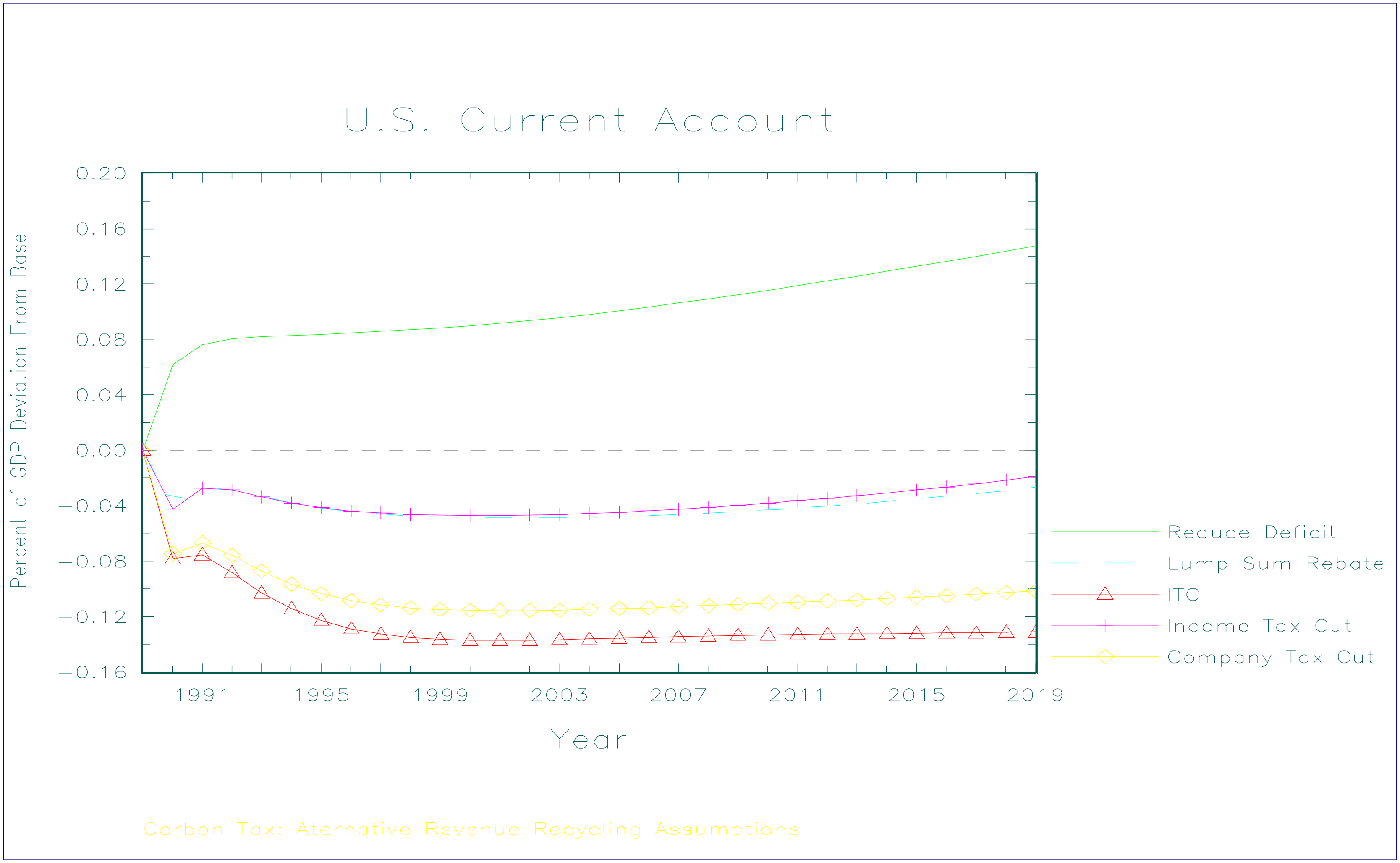

Figure 10: Consequences for the Trade Balance of a Carbon Tax Under Alternative Revenue Recycling Assumptions

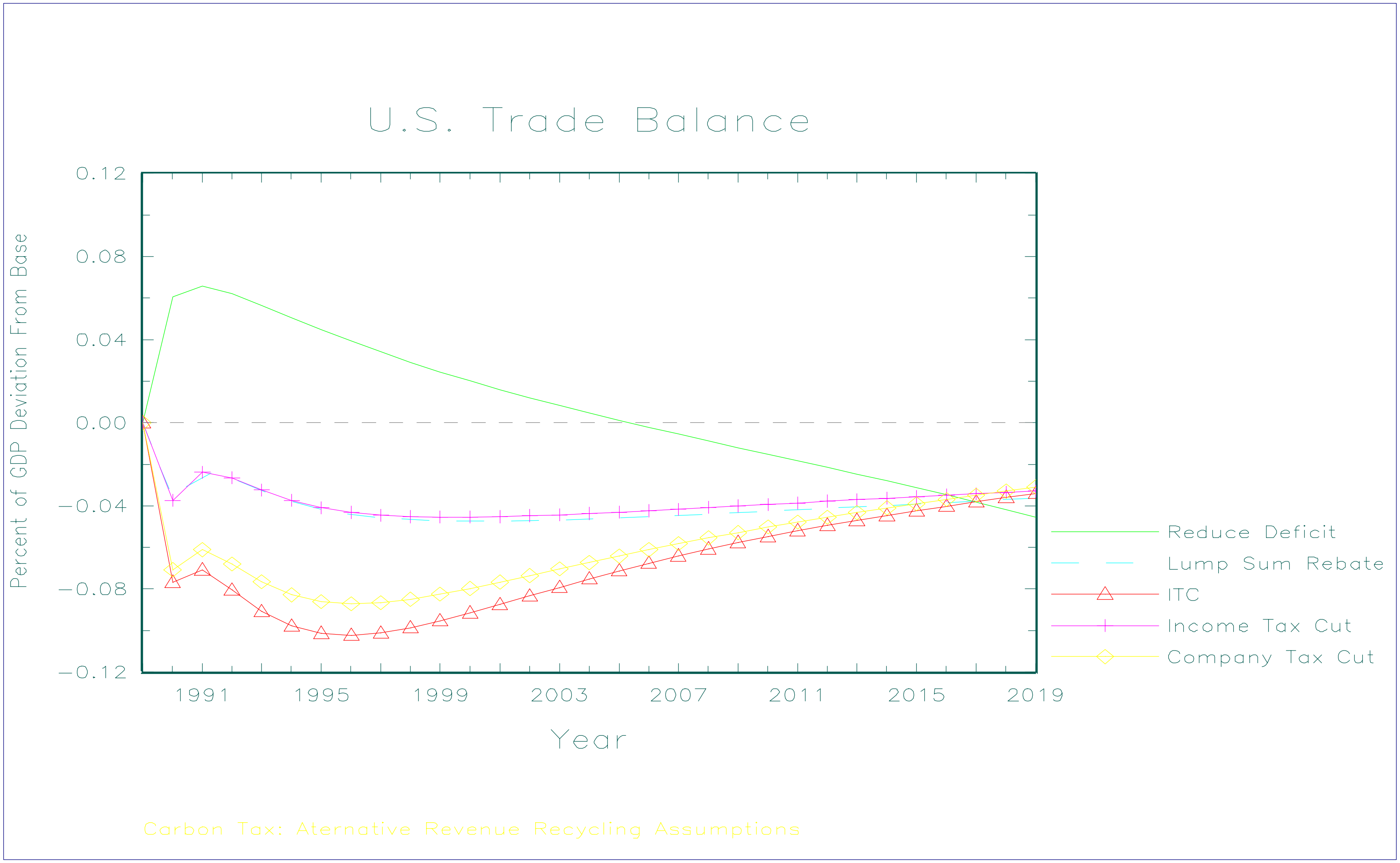

Figure 11: Consequences for the Interest Rates of a Carbon Tax Under Alternative Revenue Recycling Assumptions

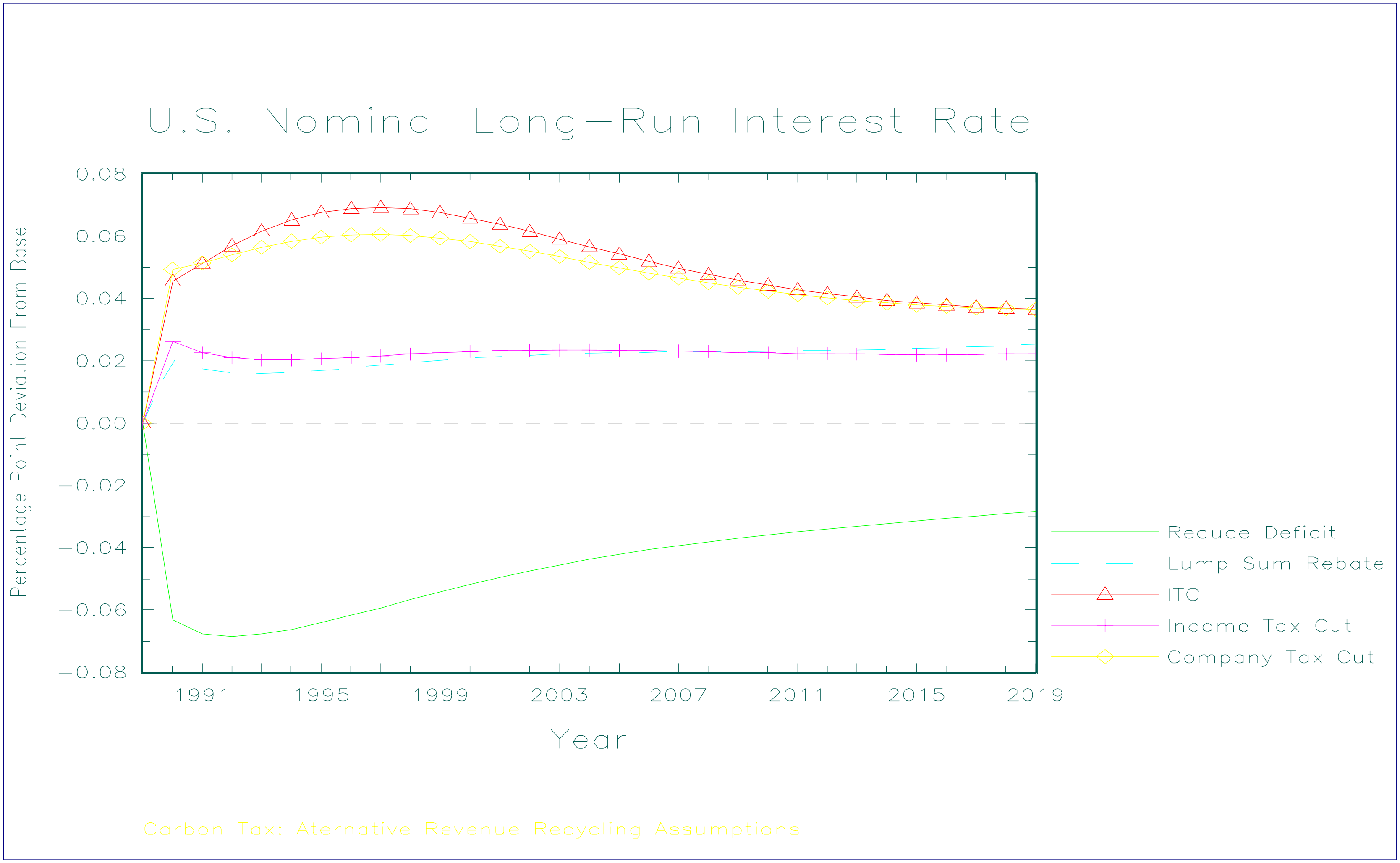

Figure 12: Consequences for Exchange Rates of a Carbon Tax Under Alternative Revenue Recycling Assumptions

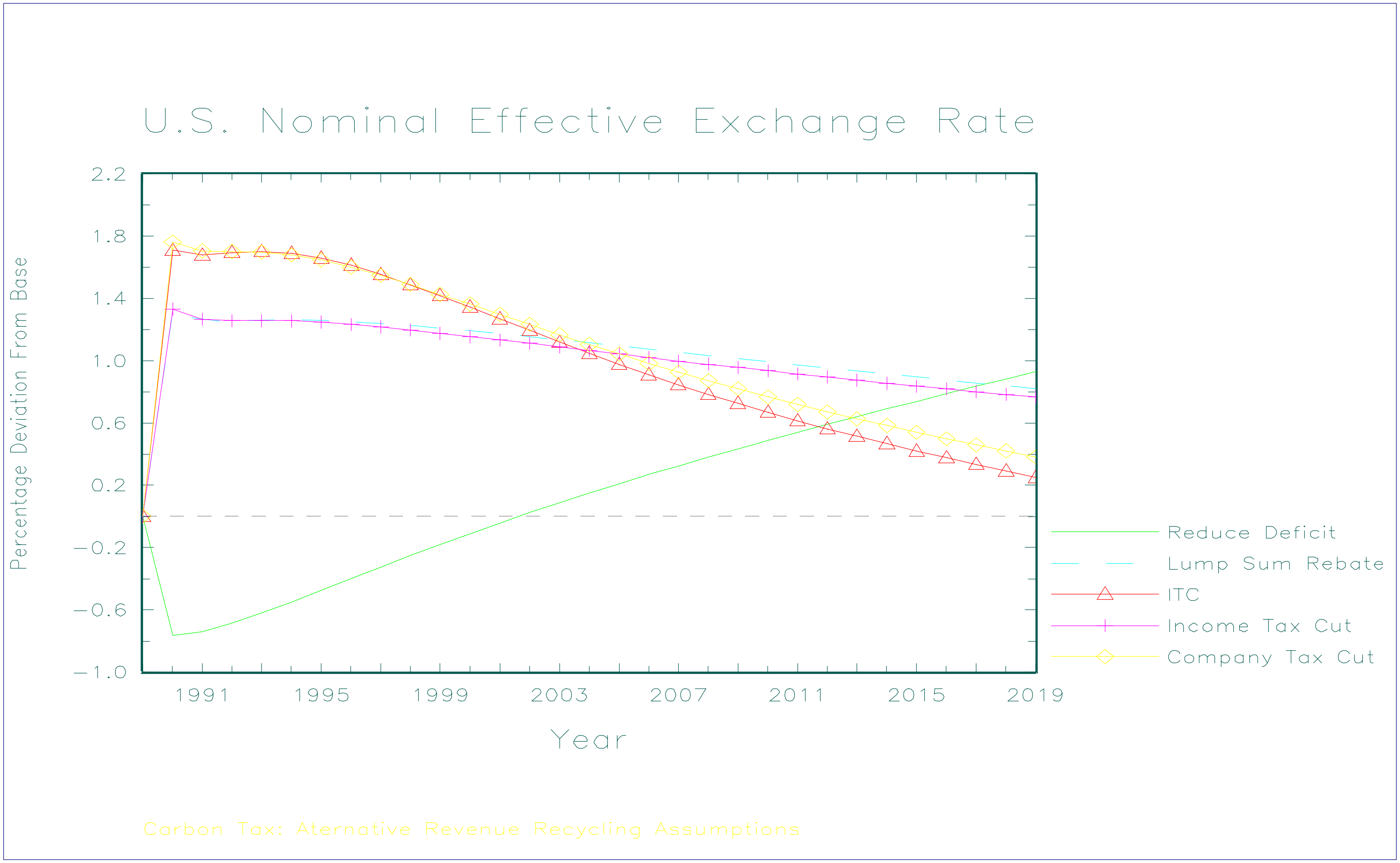

Figure 13: Capital Stock in the Electric Utilities Sector with a Carbon Tax Under Alternative Revenue Recycling Assumptions

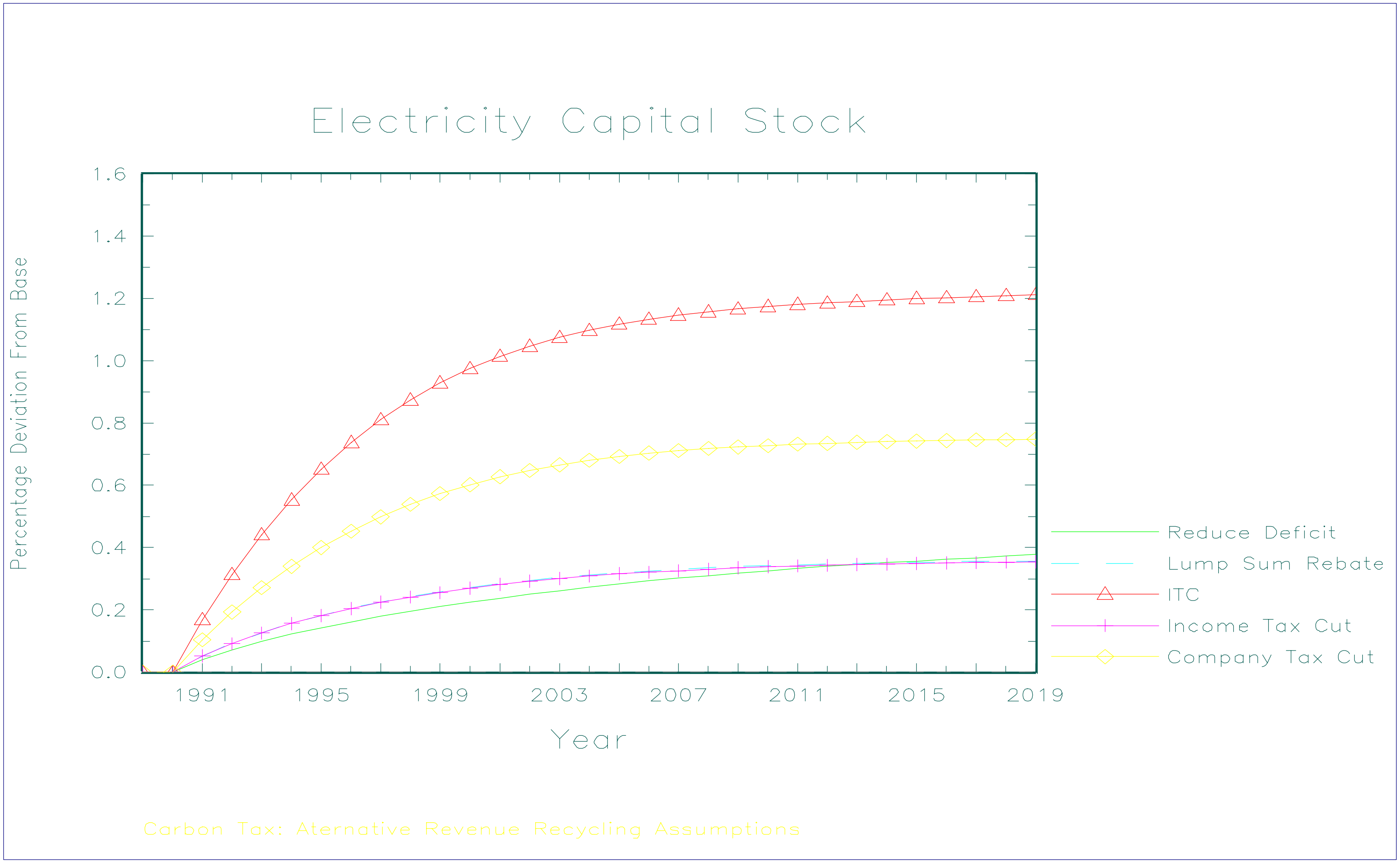

Figure 14: Consequences for the Refined Petroleum Capital Stock of a Carbon Tax Under Alternative Revenue Recycling Assumptions

Figure 15: Consequences for the Coal Mining Capital Stock of a Carbon Tax Under Alternative Revenue Recycling Assumptions

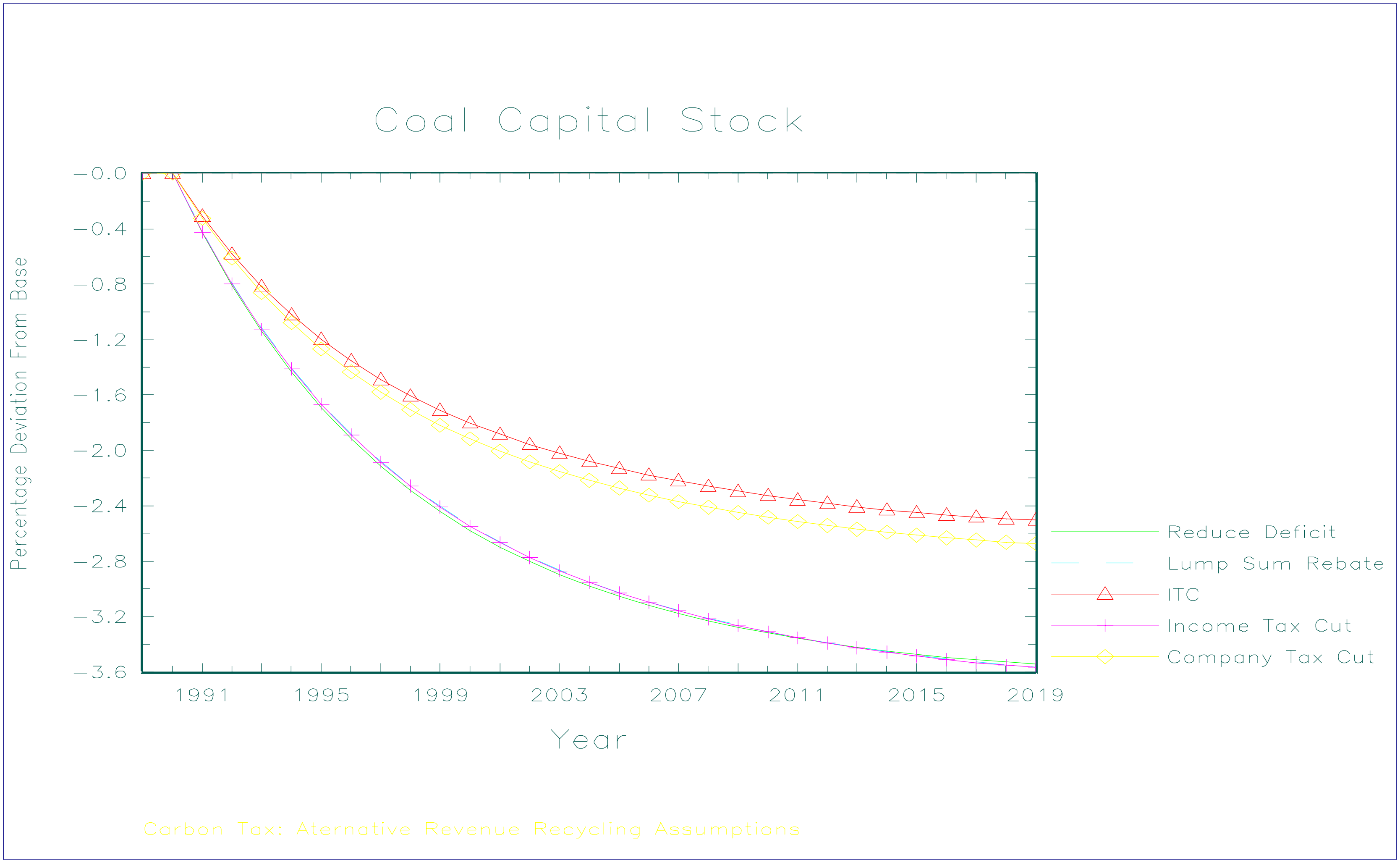

Figure 16: Consequences for the Oil & Gas Extraction Capital Stock of a Carbon Tax Under Alternative Revenue Recycling Assumptions