ENVIRONMENTAL POLICY AND INTERNATIONAL TRADE

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Environmental Policy and International Trade

ABSTRACT

This paper explores the empirical link between environmental policy and international trade. Using an estimated global simulation model, the paper focusses on the extent to which international trade flows are redirected as a result of unilateral versus multilateral taxes on the emission of carbon dioxide. We find that a carbon tax in the United States produces little redirection of trade either in the short run or the long run because electric power generation and local transportation are by far the most carbon intensive activities and both are largely non-traded. We also illustrate the importance of the assumptions about the way in which the revenue from the carbon tax is recycled. We find that the revenue recycling assumption has important macroeconomic implications for saving and investment balances and therefore for the adjustment of trade flows.

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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 choose to have 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.

Although these studies show that changes in trade flows might, in theory, offset a geographically-limited global warming policy, they do not provide much guidance on the empirical question of whether the effect is large or small. In this paper we attempt to shed light on this question by using an econometrically-estimated, multi-region, multi-sector general equilibrium model to compare the effects of a unilateral U.S. carbon tax with a multilateral tax imposed throughout the OECD. Other models used to study global warming have been largely unable to examine this question because they either: focus on a single country (Jorgenson and Wilcoxen (1991a,b) and Goulder (1991)); have multiple regions but no industrial disaggregation (Edmonds and Reilly (1983), Barnes, Edmonds and Reilly (1992), Cline (1989), and Manne and Richels (1990,1992)); or do not have complete integration of international asset flows and exchange rate determination (Whalley and Wigle (1990), Rutherford (1992), Felder and Rutherford (1992), and Burniaux, Martin, Nicholetti and Martins (1991a,b)).

Our results suggest that a carbon tax would produce little redirection of trade in either the short or long run. In most economies, electric power generation and local transportation are by far the most carbon-intensive activities and both are largely non-traded. We find, however, that the manner in which revenue from the tax is used will have a substantial effect on GDP. In the remainder of the paper we present an overview of the model and discuss our results in more detail. We conclude by drawing some general inferences about environmental regulation and trade.

2 Key Features of the Model

In this section we present an overview of the features of our model, G-Cubed, that are important for our analysis of the trade effects of environmental regulation. A more complete description is contained in McKibbin and Wilcoxen (1995) or McKibbin and Wilcoxen (1994).[2]

G-Cubed disaggregates the world economy into the eight economic regions listed in Table 1. Each region is further decomposed into a household sector, a government sector, a financial sector, the twelve industries shown in Table 2, and a capital-goods producing sector. This disaggregation enables us to capture regional and sectoral differences in the impact of alternative environmental policies. In the remainder of this section we present an overview of the theoretical structure of the model. To keep notation as simple as possible we have not subscripted variables by country except where needed for clarity. The complete model, however, consists of eight of these submodels linked by international trade and asset flows.

Table 1: List of Regions

United States
Japan
Australia
Other OECD (ROECD)
China
LDCs
Eastern Europe and the Former USSR (EEB)
Oil Exporting Developing Countries (OPEC)

[2] The notation used in this section is somewhat different from that used in the other papers in order to clarify the exposition.

Table 2: Industries in Each Region

1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
6	Other Mining
7	Agriculture, Fishing and Hunting
8	Forestry and Wood Products
9	Durable Manufacturing
10	Non-Durable Manufacturing
11	Transportation
12	Services

Producer Behavior

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 has the following form:

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

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

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

where X_E is the industry's input of energy, X_j is the quantity of input j, and A_E, δ_j and σ_E are estimated parameters which vary across industries. As before, A_E and the δ parameters also vary across countries. The materials aggregation is defined in a similar manner.

In order to estimate the parameters in these equations we constructed a time-series data set on prices, industry outputs, value-added, and commodity inputs to industries for 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.[3] 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.[4] 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

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3 A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes.

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

colleagues to decompose the value added rows of the tables,[5] and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices.

Table 3 presents maximum likelihood estimates of the substitution elasticities for each industry; standard errors are shown in parentheses.[6] A number of the elasticities could not be estimated (the estimation procedure failed to converge) or had the wrong sign. In such cases we examined the data and imposed elasticities that seemed appropriate; these values are shown in the table without standard errors. For most of the imposed parameters the data suggest that there may be 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. The distributional parameters for the KLEM tier are shown in Table 4. When all prices are unity, these will be the value shares of capital, labor, energy and materials, respectively.

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[5] 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.

[6] The estimation was done 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.

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)

Table 4: Estimated Production Share Parameters

Sector	Capital	Labor	Energy	Mat.
1	0.3851	0.2150	0.2585	0.1413
2	0.2466	0.1332	0.5799	0.0403
3	0.0736	0.0555	0.7592	0.1118
4	0.3669	0.3058	0.1088	0.2185
5	0.5849	0.1670	0.0497	0.1984
6	0.2302	0.3214	0.0698	0.3786
7	0.1382	0.2471	0.0194	0.5953
8	0.1140	0.2747	0.0251	0.5862
9	0.0682	0.3402	0.0312	0.5604
10	0.1034	0.2613	0.0167	0.6186
11	0.1263	0.4876	0.0776	0.3086
12	0.1942	0.4764	0.0312	0.2982

To parameterize the other regions we impose the restriction that substitution elasticities are equal throughout the world. 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)). However, the share parameters for other regions corresponding to individual countries (Japan, Australia, China, and approximately the Eastern Europe and Former Soviet Union region) are derived from input-output data for those regions and are not set equal to their U.S. counterparts. The share parameters for the remaining regions, which are aggregates of individual countries, are calculated by adjusting U.S. share parameters to account for actual final demand components from the aggregate national accounts data for each of the regions. 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 the extremes of assuming that the regions share common technologies and of allowing the technologies to differ across regions in arbitrary ways. Finally, the regions also differ in their endowments of primary factors and patterns of final demands. The main limitation of this approach is that there are very few benchmark input-output tables so our data set contains few observations. The problem is severe outside OECD countries.

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. 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). We represent this decision using a two-tier CES function, although in this version of the model data limitations have forced us to impose unitary substitution elasticities. We assume that all agents in the economy have identical preferences over foreign and domestic varieties of each particular commodity.[7] We parameterize this decision using trade shares based on aggregations of the 4-digit level of the United Nations SITC data for 1987. 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 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. The difference between J and I may be interpreted many ways;

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[7] 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.

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 and τ_4 is the investment tax credit.

Following Hayashi (1979), the investment function above is modified to improve its empirical properties by writing J as a function not only of q, but also of its current capital income 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 weight on optimizing behavior, 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. However, we estimate the parameters of this function from price and quantity data for the final demand column for investment.

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 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.[8] 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-

[8] This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable.

constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. Under this specification, the value of each period's consumption is equal to the product of the time preference rate and household wealth:

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

Based on the evidence cited by Campbell and Mankiw (1987) and Hayashi (1982), however, we assume that only a portion of consumption is determined by these intertemporally-optimizing consumers and that the remainder is determined by after-tax current income. This can be interpreted as liquidity-constrained behavior or as permanent income behavior when household expectations are backward-looking. Either way we assume that total consumption is a weighted average of the forward looking consumption and backward-looking consumption:

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

where β is the share of optimizing households and γ is the marginal propensity to consume for the liquidity-constrained or backward-looking households. Following McKibbin and Sachs (1991) we take β to be 0.3.

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.[9]

The supply of household capital services is determined by consumers themselves who invest

[9] 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 relax it in future work.

in household capital in order to generate a desired flow of capital services. We assume that capital services are proportional to the household capital stock. As in the industry investment model, we assume that investment in household capital is subject to adjustment costs.

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. 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 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 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)).

International Trade and Asset Flows

The eight regions in the model are linked by flows of goods and assets. Flows of goods are determined by the bilateral import demands described above. These demands are summarized in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries. There is one 8 by 8 trade matrix for each of the twelve sectors for each country.

Trade imbalances are financed by flows of assets between countries. We assume asset markets are perfectly integrated across the OECD regions. With free mobility of capital, 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:

$$i_k = i_j + \frac{dE_k^j/dt}{E_k^j} \tag{10}$$

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

For the non-OECD countries we also make the assumption that exchange rates are free to float at an annual frequency. We also assume that capital is freely mobile within the regions and between the regions and the rest of the world. This may appear to be overly simplified especially when many developing countries have restrictions on short term flows of financial capital. The capital flows in the model are the change in the current account and so are both flows of short term financial capital as well as direct foreign investment. In many countries with constraints on financial instruments there is nonetheless significant flows of direct foreign investment responding to changes in expected rates of return that we need to capture. Future work will focus more on modelling financial markets in the developing regions of the model. In addition, we 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.

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.

Money Demand

Finally, we assume that money enters the model via a constraint on transactions. We use a money demand function in which the demand for real money balances is a function of GDP and short-term nominal interest rates:

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

where 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.

Solving the Model

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 (we denote this rate by "n"). Next, we must make base-case assumptions about the future path of the model's exogenous variables in each region. The most important of these variables are shown in Table 5.

We assume that in all regions the long run real interest rate is 5 percent. The other assumptions we use are shown in Table 6.

Table 5: Key Exogenous Variables

- population growth by region;
- productivity growth by sector by region;
- energy efficiency improvements by sector by region;
- tax rates by region;
- fiscal spending patterns on each sector's output by region;
- monetary policy by region
- real price of oil;
- other exogenous shifts in spending patterns..

Table 6: Regional Assumptions Used in Generating the Baseline

	USA	Japan	Aust	ROECD	China	LDCs	EEB
Population growth	0.5%	0.0%	0.8%	0.7%	1.5%	1.0%	0.5%
non-energy productivity growth	2.0%	2.5%	2.2%	2.3%	4%	2.5%	2.0%
energy sector productivity growth	1.5%	2.0%	1.7%	1.8%	4%	2.5%	1.5%
energy efficiency growth	1%	1%	1%	1%	1%	1%	1%
tax rates	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels
fiscal spending	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares	1990 shares
monetary policy (fixed money growth rate)	2.9 %	1.25 %	1.64 %	3.98 %	12.84 %	6.48 %	23.81 %
real oil price	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels	1990 levels

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050 using 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 7. 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 7: 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

3 Unilateral vs Multilateral Carbon Tax Policies

We now present results from two G-Cubed simulations designed to investigate the link between trade flows and environmental policy. In each simulation an unexpected permanent carbon tax of $US15 per ton of carbon is levied in the United States beginning in 1990. In one simulation the U.S. introduces the tax unilaterally while in the other the tax is introduced simultaneously in all OECD countries. In both cases we assume that carbon tax revenues are used to lower the budget deficit in the levying country.

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. By 2005, the cyclical effects of the tax have worn off and GDP has recovered 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 tends to reduce the deficit in both simulations (since government spending is exogenous and held constant). The fall in GDP offsets this to some extent by causing the overall tax base to erode. 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. Offhand, this is not what one would expect. Since the tax raises U.S. production costs relative to those in the rest of the world, one might expect the balance of trade (and hence the current account) to deteriorate. Our result comes about because the reduction in government borrowing lowers U.S. interest rates. This causes a drop in capital inflows as investors shift assets toward higher-yielding foreign securities. The $US depreciates which improves the U.S. trade balance. The improvement in the current account is therefore the flip side of the deterioration 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 effect disappears under the OECD-wide policy because then there is little change in relative rates of return between the U.S. and the rest of the world. In either case, these results are driven entirely 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 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 fact 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 at the level of aggregation used in the model. Thus, 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. At the model's level of aggregation, however, energy costs are a very small portion of industry or household expenses, so there is little effect on prices or demands downstream. 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.[10] 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. By 2020, 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.

[10] Gas utilities are omitted to save space.

4 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 8. 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.[11]

Table 8: Alternative Revenue Recycling Assumptions

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

The results for real GDP under a unilateral carbon tax are shown in Figure 9. Several points are evident. First, deficit reduction leads to the largest short run decline in real GDP, about -0.25 percent relative to the base case. This occurs because the main effect of deficit reduction is to reduce capital inflows, which has little effect on the economy's endowment of productive resources. The results for GNP (not shown) are somewhat more positive, reflecting the increased U.S. ownership of assets.

Where the revenue is recycled as either a lump sum transfer to households or as a cut in the

[11] 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).

income tax rate, the short-run fall in GDP is reduced to -0.2 percent. However, this leads to a somewhat larger long run fall in GDP than if the fiscal deficit is reduced (-0.16 versus -0.12 percent). 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.[12]

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 deteriorate. 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).[13] 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

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[12] 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.

[13] 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.

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 capital stock rises even while output (not shown) is falling. 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-energy sectors reduce the overall cost of reducing carbon emissions. Even though these revenue policies have similar effects on the energy industry there are large differences in the path of GDP.

5 Conclusion

Based on our results, we conclude that a modest unilateral carbon tax is unlikely to cause much trade redirection. We find 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.

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