Double Dividend Environmental Taxation and Canadian Carbon Emissions Control

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La possibilité d'utiliser des revenus en provenance des taxes environnementales pour réduire d'autres distorsions dans le système fiscal (la soi-disant approche à "double dividende") a récemment fait l'objet de nombreuses discussions. Le présent article passe en revue le débat actuel et présente des preuves empiriques suggérant que l'approche à double dividende peut réduire considérablement le coût du contrôle des émissions de CO_2 au Canada, et peut-être éliminer les réductions de bien-être collectif et de production à la suite de la mise en oeuvre d'une taxe sur le carbone.

The possibility of using revenues from environmental taxes to reduce other distortions in the tax system (the so-called double dividend approach) has been much discussed recently. This paper reviews the current debate and presents empirical evidence to suggest that the double dividend approach can significantly reduce the costs of CO_2 emissions control in Canada and possibly eliminate aggregate welfare and output reductions due to implementation of a carbon tax.

INTRODUCTION

This paper explores a new approach to the design of environmental policy, and shows how its application to carbon emissions control in Canada can reduce the expected costs of action on global warming. The policy mechanism is called "double dividend" taxation, in which the revenue generated by putting a tax on pollution emissions is used to finance reductions in other taxes elsewhere in the economy. Some of the literature in which this idea is developed, and the ongoing debate over its merits, is reviewed in the next section. Macroeconomic simulations are then presented which show that the double dividend approach substantially changes the expected costs of implementing a carbon emissions control policy in Canada. We impose a carbon tax sufficient to reduce CO_2 emissions by 12.5 percent off a year 2000 base case, which is approximately what will be required for Canada to meet the Rio target. Of the options for recycling tax revenues we consider, reducing payroll taxes has the most favourable outcome: no aggregate effect on welfare,[1] and an increase in output (GDP), real wages and employment, compared to the base case. By contrast, other revenue recycling rules which generate the same emissions reduction cause gross[2] welfare, output, and employment losses. In none of these cases do we measure the benefits associated with emissions reduction, but since the emissions reduction is identical across all scenarios, the implied benefit is constant. So the simulations presented here generate a ranking of preferred revenue recycling rules, and show that one of them may allow Canada to achieve substantial emissions reduction with no aggregate economic losses.

As with any numerical simulation, it is important to understand the assumptions and features of the model being used. In this paper a Computable General Equilibrium (CGE) model is employed. Details on its construction are in the Appendix.

Review of the Literature

A tax generates a discrepancy between the price paid by a buyer and received by the seller. Since prices are the signals which coordinate efficient resource allocation, such discrepancies reduce economic efficiency and consumer welfare by an amount greater than the revenue collected by the state. This is referred to as the "deadweight loss" or "excess burden" of the tax system. The phenomenon of deadweight loss is the basis for standard arguments in public finance that taxes reduce economic welfare.

The analysis of taxes in the context of pollution policy has generated a contrasting result however. Environmental economists argue that when some social costs associated with production and consumption are not borne by the respective producer or consumer, but are shifted (externalized) to society, this distorts prices, and so reduces economic welfare. In this case however, the seller's price is artificially low (since the producer has externalized part of the social cost of production), so a tax which raises the price of the good can increase welfare. If we denote the marginal social damages (measured in monetary terms) due to pollution as *MD*, the elementary proposition of environmental economics (see e.g., Baumol and Oates 1988) is that a tax *t* set according to

$$t = MD$$

is welfare-enhancing.[3] That is, while a "regular" tax causes a welfare loss, a pollution tax causes a welfare gain, because it corrects an externality.

Lee and Misiolek (1986) suggested that these effects should be paired to generate two types of efficiency gain simultaneously. A tax on pollution raises welfare and raises money for the government, and the money raised can then be used to reduce a "regular" tax, which, by decreasing the excess burden of the tax system, generates a further increase in economic welfare. Hence the name, coined later, "double dividend." Because of the potential welfare gain from revenue recycling, Lee and Misiolek concluded that a pollution tax should actually be greater than the value of the marginal social damages from the pollution. Following the terminology of Parry (1995), denote by *RE* the "revenue effect": the (money-measured) improvement in welfare that can be gained by using the pollution tax revenue to fund a marginal reduction in the most distorting of the pre-existing taxes.[4] Then Lee and Misiolek argue that the pollution tax should be

$$t = MD+RE.$$

Note that, even if we are uncertain about the size of *MD*, as is usually the case, we know $RE>0$, so as long as $MD>0$ we can be certain that a pollution tax will be welfare-improving. Based on this argument, some economists advanced a strong "double dividend hypothesis," which states that combining a pollution tax with a revenue-neutral reduction in another distorting tax *always* increases welfare, irrespective of the welfare benefit of reducing pollution. In the early 1990s, this argument generated much interest amongst economists (e.g., Pearce 1991; Nordhaus 1993), and policymakers, especially in the context of discussions about how to respond to global warming, where meaningful estimates of marginal damages are very difficult to generate.

Based on some recent theoretical work, however, environmental economists have retreated from the strong double dividend hypothesis. Bovenberg and de Mooij (1994), Parry (1995), Fullerton (1997), and others, noted that models such as that of Lee and Misiolek (1986) and the numerical simulation model in Nordhaus (1993) implicitly assume other tax rates are zero. They instead explored analytical models which derive the optimal tax on a polluting activity in the presence of pre-existing tax distortions. They find that, in addition to the marginal-damage reduction effect (*MD*) and the revenue effect (*RE*), a pollution tax generates an "interdependency" effect, which we denote *IE*, again using the terminology of Parry (1995). Consider an economy where the government's budget is entirely financed by a tax of *x* percent on nominal labour income. A pollution tax will increase the cost of production, thus raising the cost of consumer goods and reducing real wages. As real wages fall, the labour supply falls and the excess burden of the income tax will typically increase. This increase in the distortions in the labour market, brought about by a tax on pollution, is the so-called "interdependency effect" or *IE*. If it is welfare-reducing (as it is in the three papers cited above), accounting for the *IE* in setting the pollution tax rate will lead to a lower optimal tax level than suggested by the analysis of Lee and Misiolek (1986). The formulae in Parry (1995) and Fullerton (1997) are additive, and we can summarize them as:

$$t = MD + RE - IE$$

which states that the optimal tax *t* on pollution should equal marginal damages plus the benefits derived from reducing other taxes, less the costs arising from the exacerbation of pre-existing distortions by the new pollution charges.

If *RE*>*IE*, then the pollution tax should be greater than *MD*. Or, equivalently, we would be certain of generating a welfare gain even if the damage reduction effect were nil. A pollution tax (of some magnitude) can be adopted on pure efficiency grounds, regardless of its environmental merits. While there have been a number of versions of the "double dividend hypothesis" (see Goulder 1994 for a review), many authors now use the term to refer to this outcome.

If *RE*<*IE*, then the optimal pollution tax should be less than marginal damages. Some recent authors, including Parry, have suggested that this will generally be the case, therefore they reject the double dividend hypothesis. However, these arguments make use of simple partial or general equilibrium models which usually assume that the economy consists of a single firm with a linear production function and two or three outputs, a single factor (labour), no savings, no investment, no fixed capital, no intermediate goods or international trade, and only one or two pre-existing *ad valorem* taxes. Parry (1995) uses some assumed values of aggregate elasticities in a simple graphical model to suggest that the optimal tax on polluting production should be only 63-78 percent of *MD*. But this result is sensitive to the substitution elasticity between the polluting good and labour supply (or, equivalently, leisure demand). It is initially assumed to be unity, however if it is only 0.5 the optimal ratio of *t* to *MD* rises to between 86 and 157 percent.[5] So even in a simple model, unambiguous predictions about the possibility of a double dividend are elusive. Bovenberg and Goulder (1995) analyze a model with two factors, labour and capital, and find that the relative magnitudes of the revenue and interdependency effects vary depending on the prior characteristics of the tax system.[6] They conclude that "the presence or absence of the double dividend must be settled empirically, as it depends on initial conditions, the incidence of the pollution tax, and the way that environmental tax revenues are 'recycled' to the economy" (p. 9). Consequently, there is considerable need at present for more formal empirical investigation.

Such research has unfortunately been rather limited, considering the policy implications.[7] Positive findings could, for instance, provide potentially significant help developing an international tax policy for carbon emissions control. No country acting alone, regardless of the aggressiveness of its control strategy, would be able to significantly alter the trajectory of climate change. So, from a national point of view, most policies for controlling carbon emissions appear to have high, certain and visible costs, while yielding low, uncertain and largely invisible benefits. Not surprisingly, the incentives for action are very weak, and major initiatives appear unlikely in the near future. The possibility for double dividend environmental taxes to generate unilateral benefits to carbon emissions control is a promising mechanism for motivating the requisite broad levels of participation in a climate change agreement, so empirical investigation is needed. To date however only a few such studies have been attempted.

Shackleton *et al.* (1992) presents evidence from four dynamic US models to show that if reductions in profits taxes or increases in an investment tax credit are used to rebate carbon tax revenues, efficiency gains of up to 1.7 percent of US GDP could be realized, even while substantial cuts in CO_2 emissions are occurring.[8] Shah and Larsen (1992) use static partial equilibrium models for two developed countries (the US and Japan) and three developing countries (Indonesia, Pakistan, and India). Reductions in capital income taxes financed by a US$10 per ton carbon tax yield gross welfare increases in some of the countries, especially the developing countries, where the pre-existing profits taxes are higher.

Barker, Bayliss and Madsen (1993) use a multisector industry model to look at the effects on the UK of an EC carbon tax designed to reduce carbon dioxide emissions by 12 percent by 2005. Among revenue recycling options, deficit reduction causes the familiar-looking GDP loss (against base) of about 0.4 percent; however, an income tax offset generates a 0.1 percent GDP increase, while a VAT offset generates a 0.2 percent GDP increase.

This study will show that if Canada imposes a carbon tax in the year 2000 to force estimated carbon emissions down to 1990 levels, and uses the money to finance reductions in payroll taxes, consumer welfare would be unchanged and GNP would increase by 0.6 percent in the short-run. On the other hand, if lump-sum transfers were used to recycle the revenue, welfare and GNP would fall by 0.3 and 0.8 percent respectively.

If it can be shown that properly implemented carbon taxes can make a country better off, in purely economic terms, the uncertainty surrounding global warming would cease to be a barrier to taking action. A broadly based international tax reform could be pursued with each country participating because it believes it will benefit unilaterally, regardless of how large or small the climate effects are. This initial, wide level of participation would be critical for generating a discernible level of environmental improvement, which might in turn motivate continued participation. The possibility of this scenario being realized requires the establishment of a wide body of evidence on the efficiency value of carbon taxes. This paper adds to this effort, focusing on one of the developed world's major emitters of greenhouse gases.

It is important to stress that there is nothing special about environmental taxes in discussing tax reform. As long as there already exists at least one tax which is more distortionary than a new tax on fossil fuels, the potential will exist for efficiency gains through a revenue-neutral switch away from the more burdensome revenue source. This is true for any pair of taxes, not just carbon taxes: as long as one tax is less distortionary than another, an efficient tax reform is possible. Since, presumably, there are other taxes which are less distorting than carbon taxes, the same kind of argument could be used to support *removing* the carbon tax in another round of tax reform. The empirical literature cited above, and the present study, examine only local improvements in the mix of taxes, and do not try to identify a globally optimal tax policy. In effect, the presence of suboptimal taxes represents an unrealized source of growth for an economy, and this literature looks at whether some of this untapped potential could be used to cover the welfare costs of reducing CO_2 emissions.

The Carbon Tax Simulations

The model to be used is a static Computable General Equilibrium model of the Canadian economy. Before presenting the simulations we discuss the nature of CGE models in general, and of the present model in particular. A more complete description of the model is in the appendix.

The principle of demand and supply is familiar: shortages cause prices to rise, surpluses cause prices to fall. When the quantity supplied equals the quantity demanded, there is no pressure for the price to change, so it is the "equilibrium" price. When all markets are in equilibrium the economy is said to be in a "general equilibrium." The economic interpretation of general equilibrium is that resources and factors of production are fully and efficiently utilized: no activity can expand without some other activity contracting, and no one can be made better off without someone else being made worse off. Hence it characterizes the maximum capacity of an economy to provide for the material welfare of its members.

Most economic analyses focus on the changes in a single market brought about by a policy change (or "shock"). For large policy shocks, though, this is an inadequate approach, since changes in one market will cause price and quantity changes to occur in other markets as well. Models which fail to account for these "second-order" effects only describe the initial changes in one market after a policy shock, implicitly assuming the rest of the economy is unaffected. But if changes occur elsewhere in the economy as well, they will feed back into the first market, amplifying the effect of the shock. So the definition of the "ultimate" or total effect of a policy shock must be revised. One definition which economists tend to favour is that the total effect of a policy is the aggregate welfare change between the *general* equilibria attained before and after its introduction.

Economists quantify such changes using Computable General Equilibrium models. These are not the same as macroeconomic forecasting models. Instead they attempt to isolate and measure the changes in the general equilibrium of an economy — its potential productivity and performance — in response to a single policy change, as opposed to predicting the actual, realized outcome of a policy change amidst all the simultaneous shocks and events to which an economy must continuously adjust. To do this, CGE models represent mathematically the determinants of demand and supply in every market, including as complete as possible a description of the cross-linkages by which changes in any one price or tax affect prices elsewhere in the economy. The model then searches out an equilibrium set of prices at which, in every market, the quantity demanded equals the quantity supplied.

Tables 1 and 2 describe the basic divisions of the model used for this study and its level of microeconomic detail. The Canadian economy is divided into six production sectors and ten commodities. There is a single aggregate household, a single level of government, and a single foreign trade sector.

We use a static equilibrium model, in which each industry has a unique, fixed capital stock, and household savings and industry investment demands are assumed to be fixed. To relax these assumptions would require developing a dynamic general equilibrium model, which is beyond the scope of the present study. Future development in this direction would be desirable.

TABLE 1
Summary of the Four Sectors and the Computation of the Equilibrium

Consumers

- Single aggregate household represented by a nested Utility Function
- 3 allocations: labour/leisure, current/future consumption, current consumption shares
- Sole supplier of labour, co-owner of capital with government and foreign sector
- Subject to income, retail, payroll taxes as well as GST
- Gross substitutability not imposed

Firms

- Technology represented by a nested profit function with capital fixed across period
- Multiple-outputs permitted
- Variable inputs and outputs chosen based on current net prices
- All firms assumed to be price-takers
- Investment demands based on profits, prices, and interest rates
- All imports flow through manufacturing and service sectors
- Subject to retail, payroll, profits taxes, GST

Government

- One level
- Revenues: taxes, deficit, investments
- Expenses: transfers to households (domestic and foreign), subsidies to businesses, consumption subsidies, labour demand, interest on debt, other expenses allocated to goods and services using estimated budget share equations.

Rest of the World

- Imports supplied elastically, exports demanded elastically
- Clears savings market at world interest rate (US prime)
- Importing sector pays tariffs
- Current and Capital Accounts balance each period

Computation of Equilibrium

- Exchange rate is the numéraire, current and capital account balance ensured by Walras' Law
- Base-case data set generated by the model based on forecasts of exogenous variables
- Values of exogenous variables fixed across policy simulations, as were savings and investment estimates

For each sector, a demand function is specified for every commodity and variable factor used (with separate functions for domestic goods and imports), and a supply function is specified for each commodity sold (with separate functions for the domestic and export markets). Each such function predicts the quantity traded as a function of current market prices and (for firms) the industry capital stock. Budget constraints apply to each firm, the household sector, the government sector, and the foreign trade sector to ensure that no agent's spending exceeds its income. The general equilibrium is defined as a set of prices and implied quantities at which all markets clear, all budget constraints hold, and all national accounting identities are satisfied.

For each factor, intermediate input and final demand commodity (including imports and exports), the appropriate tax rates are converted to *ad valorem* levels and added to prices. The model embeds considerable detail about the aggregate tax system in Canada, and allows a wide array of revenue recycling experiments. Base case average-marginal tax rates on corporations and households are computed so as to generate levels of revenue observed at the end-of-sample (1989), with some adjustments made

TABLE 2
Aggregate Sectors, Industries, Factors and Commodities

Sector	*Industry*	*Factors Supplied*	*Outputs*
Households		Labour Capital	
Firms, consisting of:			
	Agriculture		Non-durable goods
	Extraction (mines, quarries and oil wells)		Natural gas Coal Other minerals
	Refining		Refined fuels Other refinery outputs
	Utilities		Electricity Other utilities
	Manufacturing		Durable goods Non-durable goods
	Services		Services
Government		Capital	
Rest of the World		Capital	Non-competing imports All other imported goods

to reflect the estimated effects of fiscal policy since then. The major base case average-marginal tax rates used were GST 7.0 percent, corporate income tax 9.4 percent, personal income tax 22.0 percent, employees' payroll tax 2.8 percent, employers' payroll tax 9.8 percent.

To make the model suitable for assessing carbon dioxide emissions control policies, coefficients were calculated which relate fuel use to CO_2 release. Emissions per fuel type for 1986 were obtained from Beauséjour, Lenjosek and Smart (1992). These were used, along with the real quantity indices in the database assembled for the econometric work, to generate parameters which predict total emissions per index unit of fuel. Parameters were also derived which relate CO_2 emissions to manufacturing production of durables and non-durables, since certain processes in these industries are major emissions sources, over and above fuel use.[9]

Five short-run carbon tax policy experiments are shown below. In each, a tax on consumption of fossil fuels or on production of durables and non-durables is imposed, with the tax proportions reflecting the relative levels of carbon emitted as a result of the polluting activity. The tax is also applied to imports of fossil fuels, since their combustion will take place domestically, but not to imports of manufactured goods (since it is the production rather than the consumption that is polluting). Neither is any attempt made to quantify and tax the carbon content of imported goods. The model distinguishes petroleum products used as fuels and those used for non-fuel production (e.g., plastics) so as not to tax the latter.

The level of the tax per unit of carbon is determined endogenously, through the criterion that the tax must be sufficient to force a 12.5 percent reduction in carbon dioxide emissions against the base case. This is the estimate in Beauséjour, Lenjosek and Smart (1992) of the reduction required in the year 2000 to bring Canadian emissions down to the 1990 level. The scenarios differed only in the way the carbon tax revenues were recycled. The recycling rules are summarized in Table 3. Carbon tax revenues are used for, respectively, lump-sum transfers to households, reductions in the Goods and Services Tax, reductions in corporate income taxes, reductions in personal income taxes, and reductions in payroll taxes.

Table 4 summarizes some of the key aggregate results of the policy experiments. Keep in mind that no attempt is made to quantify the benefits for producers or consumers from carbon emissions control. The emissions reduction is identical in each scenario, so whatever benefits might arise can be imputed equally to the outcome of each simulation.

The first eight rows show, respectively, the carbon emissions reduction achieved (12.5 percent in each case), the carbon tax in dollars per ton, the total revenue generated, and the tax as a percentage on price for the five commodities whose production or use generates emissions. The nominal tax varies slightly across simulations because the differences in the recycling rule cause differing adjustments in economic activity. Generally, the more the recycling rule stimulates output, the higher the tax must be to produce sufficient incentives for substitution away from carbon-intensive fuel use.

Table 3
Revenue-Recycling Rules for the Six Carbon Tax Experiments

Code	*Revenue-Recycling Strategy*
LS	Lump-Sum transfers to households. No offsetting tax reductions. Transfers set so as to keep government deficit unchanged.
GST	Goods and Services Tax Reduction. Rate reduced to the level which keeps government deficit unchanged.
CIT	Corporate Income Tax Reduction. Rate reduced to the level which keeps government deficit unchanged.
PIT	Personal Income Tax Reduction. Rate reduced to the level which keeps government deficit unchanged.
PAY	Payroll Tax Reduction. Adjustment applied equally to employer and employee portions. Rate reduced to the level which keeps government deficit unchanged.

Consider the entry for Consumer Utility, or aggregate welfare. Under lump-sum revenue recycling (LS) there is a 0.3 percent welfare loss.[10] Since we do not measure the welfare effect of environmental damage reduction, and the revenue is not used to reduce distortions elsewhere in the tax system, this is an estimate of the welfare costs of carbon taxes arising purely from their own marginal excess burden and their interaction effects (*IE*) with the rest of the tax system. In the remaining four simulations the revenue is used to reduce other tax distortions, that is, to generate revenue effects (*RE*). For both GST reductions and corporate income tax (CIT) reductions, the welfare change remains at -0.3, so the revenue effects are apparently negligible. The CIT has no direct distortionary effects in this model since it is a tax on the earnings of fixed capital, and savings and investment are fixed. The GST acts much like a profits tax, since it applies to value-added within each sector, and does not distort the relative costs of inputs. It does distort the overall consumption level however. It also distorts the composition of output, since there are some exemptions to the GST, including exports and food. The exemption for exports was treated directly, and we attempted to include the food effect in the model by exempting the output of the agricultural sector from the GST. However, these distortions appear to be relatively minor, as the reduction in the GST (from 7 to 5.9 percent) also fails to generate a noticeable welfare improvement relative to the LS case.

The reductions in taxes on household incomes and payrolls do generate welfare improvements. Reducing the general income tax offsets one-third

TABLE 4
Results from the Short-Run Carbon Tax Revenue-Recycling Experiments

	Revenue-Offset Rule				
Variable	*LS*	*GST*	*CIT*	*PIT*	*PAY*
	(% deviation from base case except where noted)				
CO_2 emissions	-12.5	-12.5	-12.5	-12.5	-12.5
Tax per ton CO_2[a]	$19.64	$20.37	$19.51	$20.32	$21.68
Carbon tax revenue ($bil)[a]	$7.1	$7.4	$7.1	$7.3	$7.8
Tax as a percent on price:					
Natural gas	30.3	31.5	30.3	31.2	32.9
Coal	84.3	87.6	84.2	86.7	91.5
Refined fuels	15.6	16.2	15.5	16.0	16.9
Manufactured durables	0.2	0.2	0.2	0.2	0.2
Manufactured non-durables	1.9	2.0	1.9	1.9	2.1
Tax rate adjustment	n.a.	-15.4	-36.5	-3.8	-26.5
Consumer utility	-0.3	-0.3	-0.3	-0.2	0.0
Real GNP	-0.8	-0.5	-0.9	-0.3	+0.6
Real consumption	-0.8	-0.5	-1.0	-0.3	+0.9
Real exports	-2.5	-2.1	-2.5	-2.1	-1.3
Real imports	-1.7	-1.3	-2.0	-1.5	-0.9
Net rate of return to capital	-7.4	-7.7	-5.5	-6.1	-3.5
Government deficit (bil)[a]	15.0	15.0	15.0	15.0	15.0
Change in trade deficit (bil)[a, b]	+0.9	+1.0	+0.4	+0.7	+0.2
Real wages	-0.6	+0.2	-0.5	-0.2	+0.5
Percentage of income paid in taxes[c]	+0.8	+0.8	+0.9	-2.3	-0.5
Employment	-0.8	-0.4	-0.8	-0.1	+1.1
Household net income	-0.9	-1.3	-1.3	+0.3	+1.0

Notes:
[a]Figures are in 1989 dollars.
[b]Nominal Goods and Services Imports minus Exports.
[c]Not counting effects of tax incidence-shifting through price changes.

of the welfare cost of the carbon tax, for a net welfare effect of -0.2 percent. Reducing payroll taxes fully offsets the welfare cost of the carbon tax. The income tax reduction raises household net income enough to offset over half the loss in real consumption due to the fuel taxes, and offsets two-thirds of the loss in real wages, compared to the LS case, thus countering the drop in the labour supply. Consequently the fall in equilibrium employment and output are smaller. The payroll tax reduction is targeted specifically to employment income (63.4 percent of total pretax income in the base case) so the relative increases in output and hence consumption are stronger. We assumed that employer and employee portions of the tax are reduced equally. The real wage increases by 0.5 percent, and the increase in equilibrium employment indicates that this is driven primarily by an increase in labour demand. We shall show below that the results under this scenario are robust to substantial perturbations in the assumed labour supply elasticity.

The neutral effect on welfare under the payroll tax reduction option indicates that the revenue effect is sufficient to offset the interaction effect of the carbon tax. This is an encouraging finding. As long as the reduction in carbon emissions generates any welfare improvement, we are assured of an aggregate welfare gain under this option, without needing to actually quantify what the environmental benefits are. It therefore broadens the evidence that national carbon taxes can be implemented which generate domestic economic benefits, regardless of the effect on global climate.

The changes in welfare are not identical to the changes in GNP. While GNP and real consumption move closely together, the welfare measure also takes into account the change in work effort (or the reduction in leisure demand). Compared to the LS case, the GST and PIT outcomes are an interesting contrast, as the welfare losses are the same, but the GNP losses are divergent. With the consumption tax offset, the real wage rises and, compared to LS, consumption is higher but leisure is lower. These yield relatively higher GNP but no improvement in welfare. With the profits tax offset, the real wage falls, consumption falls slightly, and leisure stays the same. These yield relatively lower GNP, but no comparative loss in welfare. The PIT and PAY experiments affect household income directly, and in these cases the improvements in GNP and welfare move together.

This model understates the effect of reducing corporate income taxes on economic activity, since the capital stocks and investment levels are fixed. However, we can draw some inferences from the changes in the returns to capital. The payroll tax reduction scheme is more beneficial for firms than is the profits tax reduction scheme, since output is 1.5 percent higher than under the CIT option. Since the return to capital is a signal of future investment, this suggests that the PAY option may also be dominant in dynamic simulations, although the evidence for the US from Shackleton *et al.* (1992) favours capital income tax reductions for maximizing efficiency when investment effects are accounted for. This aspect will need to be explored in a dynamic CGE model.

Looking at the neutral welfare effect associated with the payroll tax reduction, the next question is whether alternative targets would generate higher or lower welfare gains. Of special interest would be the possibility that an even more stringent target might yield even greater efficiency improvements. Unfortunately, this possibility seemed to be ruled out by further experimentation. Carbon emissions reductions of 2.5 to 25.0 percent were tested, and the optimum reduction occurred at 2.5 percent for the welfare measure (at which point the gain still did not exceed 0.04 percent). The maximum GNP increase occurred at about a 15.0 percent emissions reduction. Table 5 summarizes these findings.

TABLE 5
Short-Run Welfare Changes Associated with Different Carbon Reduction Targets When Revenues Are Recycled Using Payroll Tax Reductions

	Percent Change in:		
CO_2 Emissions	*Utility*	*GNP*	*Tax Rate*
-2.5	0.0	+0.3	-7.1
-5.0	0.0	+0.4	-11.9
-7.5	0.0	+0.5	-16.7
-10.0	0.0	+0.6	-21.6
-12.5	0.0	+0.6	-26.5
-15.0	-0.1	+0.6	-31.2
-17.5	-0.2	+0.6	-35.7
-20.0	-0.3	+0.5	-39.7
-22.5	-0.4	+0.2	-42.7
-25.0	-0.7	-0.3	-43.8

Since the consumption-leisure substitution elasticity used in this model is higher than that used in much of the earlier literature, the results in the PAY column of Table 4 were re-computed using lower values, as a reliability check. The results are shown in Table 6. The first column repeats the results in the PAY column of Table 4. The second column uses an elasticity which was computed by reducing the estimated value of the consumption-leisure substitution parameter[11] by two standard deviations (from -0.12 to -0.28). This implies a substitution elasticity of 0.78 as opposed to 0.89. Since this is still higher than usual, the simulation was re-run with substitution parameter equal to -0.67, which implies an elasticity of 0.60, and with substitution parameter equal to -5.67, implying an elasticity of 0.15. This latter elasticity value has been used for some previous CGE studies which also had a single aggregate labour supply function (Shoven and Whalley 1992). As is clear from the table, these changes had minimal effects on the simulation results, allowing us some confidence that the above results are robust to alternative assumptions about the labour supply function.[12]

Further details about the short-run microeconomic effects of a 12.5 percent emissions cut are shown in Table 7. Across commodities, the largest effect is a reduction in coal use. Almost 90 percent of the reduction in emissions in each case is due to reductions in coal use. Across simulations, the change in total demand by commodity is not heavily influenced by the choice of revenue-recycling rule. Neither are the changes in output and employment

TABLE 6
Sensitivity Tests for the Labour Supply Function in the PAY Option

*Parameter Definition**	*Numerical Value*			
CES Utility Function Parameter:	*-0.12*	*-0.28*	*-0.67*	*-5.67*
Consumption-Leisure Substitution Elasticity:	*0.89*	*0.78*	*0.60*	*0.15*
Compensated Labour Supply Elasticity:	*0.60*	*0.53*	*0.41*	*0.09*
	(% deviation from base case except where noted)			
Tax per ton CO_2 (1989 Cdn$)	$21.68	$21.30	$20.77	$19.56
Carbon tax revenue (bil 1989$)	$7.8	$7.6	$7.3	$6.6
Tax rate adjustment	-26.5	-26.0	-25.1	-20.7
Consumer utility	0.0	0.0	0.0	-0.1
Real GNP	+0.6	+0.6	+0.6	+0.4
Real consumption	+0.9	+0.9	+0.9	+0.5
Real exports	-1.3	-1.2	-1.2	-1.4
Real imports	-0.9	-0.9	-0.9	-1.0
Net rate of return to capital	-3.5	-3.5	-3.5	-4.2
Real wages	+0.5	+0.4	+0.4	+0.3
Employment	+1.1	+1.1	+1.1	+0.7

Note: *The parameter in the first row implies the values in the second and third rows. For an explanation of these relationships see endnotes 11 and 12.

TABLE 7
Further Results from the Short-Run Experiments: Total Demand, Outputs and Return Rates

	Revenue-Offset Rule				
Variable	*LS*	*GST*	*CIT*	*PIT*	*PAY*
	(% deviation from base case)				
Total Demand (Including Imports)					
Natural gas	-4.0	-3.4	-3.9	-3.7	-3.4
Coal	-26.8	-27.0	-26.8	-27.0	-27.3
Other minerals	-2.9	-2.7	-2.9	-2.7	-2.4
Refined fuels	-2.7	-2.8	-2.7	-2.7	-2.7
Other refinery products	-1.3	-0.9	-1.4	-1.0	-0.5
Electricity	-2.7	-2.4	-2.8	-2.6	-2.2
Other utilities	-3.7	-3.4	-3.7	-3.6	-3.4
Manufactured durables	-1.8	-1.4	-1.9	-1.4	-0.7
Manufactured non-durables	-0.5	-0.3	-0.6	-0.3	+0.2
Services	-1.0	-0.6	-1.2	-0.6	-0.4
Outputs by Sector					
Agriculture	+0.2	0.0	+0.2	+0.2	+0.2
Mines, Quarries and oil wells	-2.9	-2.4	-2.9	-2.7	-2.4
Refineries	0.0*	0.0*	0.0*	0.0*	0.0*
Utilities	-3.7	-3.4	-3.7	-3.6	-3.4
Manufacturing	-2.6	-2.3	-2.5	-2.1	-1.3
Services	-0.5	-0.1	-0.6	0.0	+0.8
Employment by Sector					
Agriculture	+0.7	+0.3	+0.6	+0.9	+1.3
Mines, quarries and oil wells	-2.7	-2.4	-2.7	-2.4	-1.9
Refineries	+0.3	-0.2	+0.3	+0.7	+1.2
Utilities	-0.1	0.0	-0.1	0.0	+0.1
Manufacturing	-2.0	-1.7	-1.9	-1.2	+0.2
Services	-0.4	+0.2	-0.5	+0.6	+2.5
Rate of Return to Fixed Capital					
Agriculture	+1.0	-0.2	+4.4	+1.1	+1.5
Mines, quarries and oil wells	-5.7	-5.3	-2.0	-5.1	-4.1
Refineries	-15.3	-12.1	-12.6	-13.3	-9.3
Utilities	-5.6	-4.6	-10.2	+1.9	+16.7
Manufacturing	-6.1	-6.6	-2.3	-4.9	-2.5
Services	-3.2	-3.2	+0.4	-2.3	-0.6

*Refineries technology is Leontief (fixed coefficient), and with fixed capital this implies output is unchanged in response to price changes. The mix of outputs adjusts however.

by sector for Agriculture, Mining, Refining and Utilities; however, Manufacturing and Services do show some sensitivity. Since each sector has a fixed capital stock, the changes in prices of inputs and outputs are absorbed by allowing the rate of return to adjust, rather than making adjustments in the scale of operations. (In the case of Refineries, which have a fixed-coefficient profit function, output does not change at all in response to the price shock). Therefore the changes in return rates by sector are generally large relative to the changes in output levels, and the influence of the alternative revenue-recycling rules shows up as a greater volatility in this measure. The unusual volatility in the utilities sector is due to the fact that the return rate in the base case is very small, so even minor perturbations in the net revenue stream appear proportionately large. The most consistent effect is the large reduction in profitability in the refineries sector. This would suggest that capital will exit the industry in response to carbon taxes to a greater extent than for other sectors.

The increase in employment in refining is somewhat unexpected. It arises because the output of the industry is held constant, while the release of workers from other sectors reduces real wages, which in combination cause an increase in labour demand.

Conclusions

While carbon taxes would have short-run aggregate distortionary effects, they appear to be no larger than the short-run aggregate distortionary effects of payroll taxes. Consequently, a revenue-neutral swap of carbon taxes for payroll taxes would yield no overall welfare loss, irrespective of whether or not there were any economic or ecological benefits from reducing carbon emissions.

There are several strengths of the above analysis. The model compares general equilibria rather than partial equilibria. The tax system is represented in enough detail to allow proper treatment of the interaction effects of new carbon taxes with the pre-existing tax system. The parameters of the model are all estimated econometrically on a single, contemporary time-series database in which the sector and commodity definitions exactly match the aggregates used in the model. The results under the lump-sum recycling option accord closely with those generated in an earlier, independently conducted study (Beauséjour, Lenjosek and Smart 1992). The results under the alternative revenue-recycling options make sense in light of the theoretical analyses of double dividend environmental taxation.

There are several important shortcomings to this analysis as well. The short-run (fixed capital) structure of the model means that the potentially beneficial effects of reducing capital income taxes (or the public sector deficit) are not fully represented. To look at these options will require a model that computes equilibrium changes in capital usage and savings behaviour. Such a model would also allow a formal treatment of durables demand. An important aspect of the public's response to a carbon tax over time would be the change in the composition of vehicle and housing stocks, which would feed back into energy demands in important ways. It would be desirable to enhance the model so that it could account for these effects. Other topics needing to be addressed in longer term analyses include extraction cost profiles for fuels, backstop technologies, and technical change, all of which will influence the long-run response to changing patterns of energy use.

Another desirable extension would be to enhance the regional, governmental, and social detail. The distributional impacts of environmental tax policies must be taken carefully into account when deciding among policy alternatives and when considering measures to compensate those most affected by a policy's introduction.[13] And it would be useful to consider problems associated with implementing tax changes that affect several levels of government simultaneously.

NOTES

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[1]Throughout this paper the term "welfare" is synonymous with "utility" in its standard microeconomic usage.

[2]By "gross" we mean before adding in the welfare benefit derived from reducing pollution.

[3]*MD* will typically be increasing as emissions rise, but we can treat it as a constant for present purposes.

[4]A technical aside: One way of analyzing this issue is to assume that the pre-existing tax system is at a so-called second-best optimum, in which case the marginal excess burdens of all non-zero taxes must be equal. In this case a new pollution tax, viewed simply as a revenue device, can be no less distorting than the existing taxes at the margin. Therefore what we call the revenue effect could at best just offset the additional excess burden of the pollution tax. This is why, in theoretical studies such as Bovenberg and de Mooij (1994) the double dividend is ruled out. This does not affect empirical analysis, however, since actual tax systems are not second-best optimal.

[5]The upper bound corresponds to an own-price elasticity of demand for the dirty good of 0.1, as opposed to 0.4 for the lower bound.

[6]Bovenberg and Goulder use different terminology (*tax burden* and *tax shifting* effects) but the concepts are closely related to those under discussion here.

[7]There have been numerous "bottom-up" studies which look at applications of specific technical innovations in specific industrial and residential settings, which have suggested, somewhat controversially, that negative-cost procedures are available to reduce energy demand in Canada by significant amounts. For a review see Jaccard and Montgomery (1996).

[8]Not all the models can estimate welfare changes so the output effects are highlighted. The double dividend with respect to output is not found in all models; also Goulder (1995) simulates carbon taxes on the US economy with revenue-recycling against factor income and does not generate any gross output or welfare gains.

[9]Namely ammonia and cement production, evaporation of spent pulping liquors, and burning slash after logging operations. See Jacques (1990).

[10]Beauséjour, Lenjosek and Smart (1992), using a one-period CGE model of the Canadian economy, examined the costs of carbon dioxide emissions control using only lump-sum revenue recycling. They too estimate a welfare loss of 0.3 percent for the same percentage reduction in emissions, and an output loss of 0.5 percent.

[11]The consumption-leisure substitution parameter is the rho coefficient from the CES utility function, shown in Table A.5, McKitrick (1996*a*). The implied consumption-leisure substitution elasticity is the absolute value of 1/(1-rho).

[12]When evaluated at the end-of-sample data points, the four values of rho used in Table 6 imply compensated own-price labour supply elasticities of (respectively from left to right) 0.60, 0.53, 0.41, and 0.09. These were computed by using the utility function to derive the expenditure function and differentiating to obtain the compensated leisure demand function. These values span the range of econometric estimates of the aggregate compensated labour supply elasticity used for many modeling applications (see, e.g., Browning 1987, p. 14).

[13]Some information on the distributional effects of carbon taxes is in Hamilton and Cameron (1994).

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APPENDIX
Details of the CGE Model

Overview of the Model

The model is fully described in McKitrick (1996*b*). Structurally it is very similar to the CGE model developed by Ballard, Fullerton, Shoven and Whalley (described in detail in Shoven and Whalley 1992) for analyzing US tax policy. One major methodological difference is that, rather than using the standard calibration procedure, all the equations were econometrically estimated on a 29-year time series database specially constructed for the exercise. The calibration procedure has been criticized on several grounds (see, e.g., McKitrick 1996*b*, Diewert and Lawrence 1993). The calibrated parameters are unduly influenced by an arbitrarily chosen benchmark year's data, and their empirical validity is generally not testable. The elasticity values employed are mostly guesses, or at best taken from econometric estimates on data that often do not correspond to the commodities, sectors,and time period under study. The econometric method of CGE modeling, pioneered by Jorgensen (1984), avoids all these problems.

Most of the data were taken from Statistics Canada's Canadian Socio-Economic Information Management System (CANSIM), and show inter-industry and final demand transactions for each year, linked to National Accounts measures of government revenue and expenditure and to National Balance Sheet measures of changes in financial and real asset stocks. Price and quantity indices are constructed from input-output data for the specific commodity and industry aggregates used in the model.

The Canadian economy is partitioned as shown in Tables 1 and 2. The technology of each industry is summarized by a short-run CES profit function with fixed capital and constant returns to scale. Extensive multi-stage nesting was used to enhance the flexibility of the CES functions. The firm is assumed to choose a dividend level which fully disburses profits after taxes and capital consumption allowances. The capital consumption allowance is computed using estimated sector-specific depreciation rates applied to current real capital, valued at the market price of durable goods. Each domestic commodity can be sold as an export and competes with imports. A separate category of non-competing imports is also identified.

The parameters for the top-level profit function (and variable input-output equations) in each industry were estimated as a nonlinear simultaneous equations regression system. Results are shown in Table A.3 in McKitrick (1996*a*). There was a consistent upward trend in the magnitude of the own-price elasticities of demand for labour over the sample years, as well as a general downward trend in the output elasticities. The upward trend in the labour demand elasticity is an important factor in explaining the size of the revenue effects of income and payroll tax reductions. The trend in these elasticities is consistent with that found in studies of other OECD countries (Diewert and Lawrence 1993).

Aggregate outputs and inputs were broken down into basic commodity demands/supplies using a sequence of CES nesting functions. Altogether, 17 systems of nesting equations for industry outputs, and 34 systems of nesting equations for industry inputs, were estimated. Functional forms and parameter estimates are reported in McKitrick (1996*b*).

Since the input-output tables do not identify from which sectors exports come, and to which sectors imports go, these assignments have to be made by the modeler. Exports were assumed to come from the major net producers of the commodity. The usual approach in CGE modeling for treatment of imports is to invoke the "Armington" assumption, in which a fictional technology aggregates domestic and foreign goods into a composite commodity. We avoid this assumption by having the producing sectors act as intermediaries in the import market. Each sector has a specified demand function for non-competing imports, since these are identified in the input-output tables. For other goods except durables and non-durables, the manufacturing sector purchases both domestic inputs and imports. What it does not use it then re-sells to the rest of the economy. The service sector is assumed to handle transactions in durables and non-durables. The advantage of this approach is that the substitution elasticities between domestic and imported goods can be estimated based on the observed behaviour of a sector as it responds to relative price changes between domestic and foreign goods. The Armington assumption requires that we estimate the behaviour of a sector that does not actually exist.

Canada is assumed to be a small open economy, so demands for exports and supplies of imports are assumed to be perfectly elastic at prevailing world prices. This has implications for the way trade patterns respond to carbon taxes. Specifically, since the carbon tax is applied to imported fuels as well as domestic fuels, foreign suppliers cannot absorb any of the tax, but domestic suppliers can. This would overstate the gain in market share by domestic suppliers, if in fact foreign suppliers were to absorb some of a Canadian carbon tax. Since the goods in this case are relatively homogeneous, the small open economy assumption is reasonable. The carbon tax raises production costs (i.e., shifts supply functions upwards) for most goods, and since exporters cannot raise their selling prices this causes equilibrium export quantities to decline. Since import prices are not raised by the carbon tax (except for fuels, which are subject to the tax), domestic industries must adjust to a worsened competitive position, by reducing seller prices and quantities. This generates a substitution towards imports. However total imports decline in each of the experiments because domestic aggregate demand falls by enough to offset the substitution effect.

The household is assumed to maximize a top-level CES utility function defined over a consumption-savings aggregate (Full Consumption, denoted F_t) and leisure. Having determined F_t, the consumer allocates it between current consumption and future consumption (savings) using a CES aggregator, defining the price of a unit of savings as the discount factor at the current interest rate. Consumption is then allocated among commodity categories using a series of nested CES aggregators. The first nest combines natural gas, coal, refined fuels and electricity, forming the energy aggregate. Not surprisingly, the elasticity among these is fairly low (-0.22), indicating a limited ability to switch among energy types in the short-run. By comparison, elasticities are relatively higher among non-manufactured goods (-0.76), among manufactured goods (-1.77), and between current and future consumption (-1.29). The elasticity among services, energy, and the goods aggregates is quite low (-0.14), as would be expected among the major divisions of the consumer budget. Non-competing imports were assumed to enter the consumption aggregate in fixed proportions, since the share is small (about 0.5 percent) and fairly constant over the sample years.

Simple models were used to generate base case savings and investment levels for both firms and households. Since the model is short-run by design, in each counterfactual simulation the capital stocks and levels of savings and investment were held fixed.

Government Budget and Taxation

There is a single government sector which collects revenues in several ways. Direct taxes are applied to corporate profits and household earnings. A portion of corporate taxation is treated as lump-sum, to reflect the existence of minimum taxes payable even in years when no profits are earned. Indirect taxes are applied to purchases of intermediate and final demand goods, and tariffs are applied to imports. The Goods and Services Tax (GST) is applied to value-added within each production sector except Agriculture (to approximate the effect of the exemption for food). Profits and investment income accruing to foreigners are subject to withholding taxes. Indirect taxes are applied to all commodities. Payroll taxes are the sum of Canada/Quebec Pension Plan contributions, Unemployment Insurance and Workers' Compensation premiums, and provincial payroll levies. Separate rates are identified for the employer and employee portions. The government earns investment income from shares held in domestic firms, since crown corporations are included in the firm sector. Additional revenue comes from borrowing.

Government expenses each period include predetermined and endogenous budget items. The first category includes interest payments on the debt, transfers to households, transfers to nonresidents and government labour demand, the latter set according to an exogenous time path, since the government's factor demands are assumed not to be derived from an optimizing model. The second category includes transfers to firms and spending on goods and services. Transfers to firms are assumed to be based on sector-specific output price subsidies, and are thus determined by current economic activity. The budget for goods and services is the residual after total revenue has been dispersed elsewhere. Shares in real expenditures are mostly fixed, but shares of natural gas, fuel, and electricity are allowed to vary according to relative prices by a CES aggregator with an estimated elasticity of -0.05.

Commodity tax and tariff rates are based on historical levels, with sector-specific adjustments computed to reconcile the total obtained by applying the observed rates to that reported in the input-output tables. The adjustment parameters are held constant across policy simulations.

Canadian dollar indices of import and export prices were obtained from the input-output tables, and the corresponding US dollar prices were computed by applying the average Canada-US exchange rate for that year. Adjustments beyond the end-of-sample were made to reflect recent world price changes, especially in energy exports and imports.

Model Closure and Estimation

The current account is defined as the nominal value of exports minus imports, minus net dividend and interest payments to foreigners, net of withholding taxes. The dividend rate paid on shares in foreign firms is the US prime rate plus an exogenous equity premium of three percent. The capital account is defined as net foreign savings. The current account and capital account balances must sum to zero each period. Since the exchange rate is the numéraire, this constraint is satisfied as a consequence of Walras' law.

Gross substitutability between all pairs of goods was not imposed. This means that sufficient conditions for existence of a unique equilibrium are not met. Existence was not a problem, although uniqueness could not be proven, apart from the evidence provided by the fact that, in each experiment, numerous different starting values always generated the same equilibrium.