Tax Deductions, Environmental Policy, and the “Double Dividend” Hypothesis

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Recent studies find that environmental tax swaps typically exacerbate the costs of the tax system and therefore do not produce a “double dividend.” This paper extends previous models by incorporating tax-favored consumption goods. In this setting, the efficiency gains from recycling environmental tax revenues are larger because preexisting taxes distort the consumption bundle, in addition to factor markets. A genuine double dividend is then found.

Summary findings

Parry and Bento find that incorporating tax-favored consumption in models of environmental tax swaps may overturn key results from earlier studies. In particular, a revenue-neutral pollution tax (or auctioned permits) can produce a substantial “double dividend” by reducing both pollution and the costs of the tax system. The second dividend arises because the welfare gain from using environmental tax revenues to cut labor taxes is much larger when labor taxes also distort the choice among consumption goods. Indeed (ignoring

environmental benefits), the overall costs of a revenue-neutral pollution tax are negative in the benchmark simulations, at least for pollution reductions up to 17 percent, and possibly up to 42 percent.

In addition, Parry and Bento show that the presence of tax-favored consumption may drastically increase the efficiency gain from using (revenue-neutral) emissions taxes (or auctioned emissions permits) rather than grandfathered emissions permits.

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Abstract

Recent studies find that environmental tax swaps typically exacerbate the costs of the tax system and therefore do not produce a “double dividend”. We extend previous models by incorporating tax-favored consumption goods (e.g. housing, medical care). In this setting, the efficiency gains from recycling environmental tax revenues are larger because pre-existing taxes distort the consumption bundle, besides distorting factor markets. We find that a revenue-neutral emissions tax (or auctioned permits) can produce a significant double dividend—indeed the economic costs of modest emissions reductions may be negative. The efficiency gains from emissions taxes over grandfathered permits are also larger than previously recognized.

1. Introduction

In recent years there has been a good deal of debate among academics and policy makers about the interactions between environmental policies and the tax system. These debates arose in response to the so-called “double dividend” hypothesis, that is the claim that environmental taxes could simultaneously improve the environment and reduce the economic costs of the tax system. The latter effect seemed plausible, if the revenues from taxes on carbon emissions, gasoline, traffic congestion, household garbage, fish catches, chemical fertilizers, and so on, were used to reduce the rates of pre-existing taxes that distort labor and capital markets.

However, a number of recent analytical and numerical analyses have cast doubt on the validity of the double dividend hypothesis.¹ The basic point is that the hypothesis ignores an important source of interaction between environmental taxes and pre-existing taxes. Since environmental taxes cause the costs and prices of products to rise they tend to discourage (slightly) labor supply and investment, and thereby exacerbate the efficiency costs associated with tax distortions in labor and capital markets. In fact, aside from certain special cases, these studies find that the costs from this interaction effect dominate any efficiency benefits from recycling environmental tax revenues in other tax reductions. Thus, environmental tax swaps typically *increase* rather than *decrease* the efficiency costs of pre-existing tax distortions.

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¹ We do not go into the details of individual studies here since the rise and fall of the double dividend hypothesis has been discussed at length in other places. For recent surveys of the literature see Bovenberg and Goulder (1998), Parry and Oates (1998), Goulder (1995a), and Oates (1995). Our discussion is concerned with models that assume a competitive labor market, which is probably a reasonable approximation for the U.S. economy. The general equilibrium welfare effects of environmental policies are more complex in countries where the labor market contains significant institutional distortions which make the real wage “sticky” (see e.g. Bovenberg and van der Ploeg (1998)).

The models in the recent literature typically assume a uniform tax on labor (and possibly capital) income with no tax deductions. Thus, in these models the only source of price distortion created by the tax system is in factor markets. However, certain types of spending are (at least partially) deductible from labor taxes. This includes, among other things, spending on mortgage interest, employer-provided medical insurance, and other less tangible fringe benefits.² In practice, therefore, the tax system creates an additional source of price distortion: it effectively subsidizes tax-favored spending relative to all other, non-tax-favored spending. Indeed recent evidence points to the empirical significance of this second source of economic distortion. Feldstein (1998) estimates that the efficiency costs of raising extra revenues through income taxes is much larger when the substitution between tax-favored consumption and ordinary (non-tax-favored) consumption is taken into account, besides the distortionary impact in the labor market (see below).

This paper extends previous literature by exploring the implications of tax-favored consumption for the general equilibrium costs, and overall welfare effects (benefits less costs) of environmental policies. We model a static economy where households allocate their time between leisure and labor supply. Labor, along with a clean input and a polluting input (e.g. energy or fossil fuels), is used to produce two consumption goods. Expenditure on one of the consumer goods is (partially) deductible from labor taxation. U.S. data on labor market parameters is used to calibrate the model.

At first glance, one might think that if the distortionary costs of pre-existing taxes were greater than assumed in earlier studies, then the general equilibrium costs of new environmental policies would also be greater. However we find the opposite result is typical for environmental taxes with revenues used to cut personal income taxes. That is, the presence of tax-favored consumption can substantially *reduce* the costs of environmental taxes (relative to their costs in the absence of tax deductions). In fact, results on the double dividend hypothesis established in the earlier literature can easily be overturned, even under conservative estimates for the costs of pre-existing taxes. In our benchmark simulations, ignoring any environmental benefits, the net impact of an environmental tax swap is to significantly reduce the overall economic costs of the tax system for pollution reductions up to at least 50 percent. In other words the general equilibrium costs of the policy are less than the partial equilibrium costs, and by a potentially substantial amount. Indeed the overall costs pollution taxes are negative for pollution reductions up to between 19 and 33 percent in our benchmark simulations. A related point is that, in contrast to typical results from earlier studies (e.g. Bovenberg and Goulder (1996), Parry (1995)) we find the optimal environmental tax may easily exceed the Pigouvian tax.

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² There are a variety of other major deductions from federal income taxes, such as those for pension and charitable contributions, accelerated depreciation, and so on. However, for reasons discussed below, we do not consider these other deductions to be relevant for our particular analysis.

These results arise because the welfare gain from using environmental tax revenues to reduce labor taxes is higher, and perhaps substantially so, when labor taxes distort the relative prices among consumption goods in addition to the price of labor. In contrast, (roughly speaking) the interaction effect mentioned above does not change because environmental taxes have approximately the same impact on raising the price of consumption goods relative to leisure. Also, at least in the case when the pollution intensity is the same in both the tax-favored and the non-tax-favored consumption sectors, the environmental tax does not alter the relative price of the two consumption goods, and hence does not exacerbate the costs of the subsidy to tax-favored consumption. Since the gains from recycling environmental tax revenues are larger, while the cost of the interaction effect is not, the welfare costs of the environmental tax are lower—and possibly of opposite sign—than in earlier models.

We also explore the implications of tax-favored consumption for the costs of other policy instruments. We find that the costs of non-auctioned pollution emissions permits, or pollution taxes whose revenues are returned lump-sum (rather than used to reduce distortionary taxes), could be significantly greater or significantly less than found in previous studies, depending on the relative pollution intensity of the tax-favored consumption sector. In addition, regardless of the relative pollution intensity, the welfare gain from using revenue-neutral emissions taxes (or auctioned emissions permits) instead of non-auctioned permits can be dramatically higher than suggested by earlier studies. This is due to the larger efficiency gain from using revenues from environmental policies to reduce labor taxes in the presence of tax-favored consumption. In many of our simulations there is much more at stake in whether environmental policies raise revenues, and how these revenues are recycled, than the (partial equilibrium) welfare gain from correcting the environmental externality.

Our results have important implications for policy. Clearly, if a side effect of an environmental tax is to produce significant efficiency gains by reducing the costs of the tax system, this can strengthen the case for implementing the environmental policy. To our knowledge, this is the first paper to demonstrate the possibility of such efficiency gains in a static general equilibrium model, without making some special assumptions (e.g. that the polluting good is a complement for leisure). Moreover, cost/benefit analyses of whether environmental policies are likely to enhance social welfare or not are often hampered by the difficulty of quantifying environmental benefits. If—due to the side benefit from reducing the costs of the tax system—the overall costs of an environmental tax would be small or negative, it may not be necessary to know the benefits from environmental improvement in order to justify a modest environmental tax on cost/benefit criterion. *However*, as demonstrated in other studies (Parry (1997), Parry *et al.* (1999)), if revenues are *not* used to increase economic efficiency the overall welfare effects of a Pigouvian tax can be negative, even when environmental benefits are significant.

Our model is generic rather than being calibrated to a specific pollutant. In this respect, our results may provide a rough “back-of-the-envelope” indication about how interactions with the tax system can change the results from a partial equilibrium welfare analysis, without the need to develop pollutant-specific general equilibrium models. However, as we discuss, there are certain special cases to look out for where tax interactions are more complex (e.g. when externalities have feedback effects on labor supply).

As discussed below, our paper is simplified in a number of respects and is only meant to be a preliminary attempt at exploring the implications of tax deductions. Since our analysis is static it does not capture the impact of the tax system on distorting the consumption/saving decision or the choice among different investment goods. In this respect, our results may be conservative. Furthermore, the distortion between the marginal social benefit and marginal social cost in the market for tax-favored consumption is a good deal more complicated than assumed in our analysis. There are a number of externalities and other policy interventions that impinge on this market, although the empirical importance of these factors, and whether their net impact is to diminish or magnify the size of the subsidy distortion, is unclear. Another caveat is that the main effect of tax deductions in our analysis is to increase the efficiency gains from recycling environmental tax revenues over and above those in the labor market. For these deductions to make much difference however, the tax expenditures involved must be significant relative to total labor tax revenues. This means that “small” tax expenditures, like those for employee parking, only trivially affect our results. However, as we discuss, these types of deductions become more significant if they apply directly to the market that is being regulated.

The rest of the paper is organized as follows. Section 2 discusses the welfare effects of alternative environmental policies in the presence of tax-favored consumption. Section 3 describes our numerical model and Section 4 provides the simulation results. Section 5 discusses possible generalizations to the analysis and Section 6 offers conclusions.

2. Conceptual Framework

In this section we explain the different components of the welfare effects of alternative environmental policies in the presence of (partially deductible) labor taxation, with the aid of diagrams and certain key formulas. This provides a conceptual framework for interpreting the subsequent numerical results. We provide a more rigorous mathematical model, and the derivation of the formulas, in Appendix A and B.³ At the end of this section we relate our results to those in earlier studies.

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³ The mathematical derivations of the welfare effects (see Appendix A) are similar to those in several recent models of environmental policies in the presence of labor taxes (e.g. Goulder *et al.* (1997), Parry *et al.* (1999)). In particular, the analytical model in Parry *et al.* would be almost equivalent to that in the current paper, following the

A. Assumptions

Consider a static economy where two final goods X and Y are produced using labor and intermediate goods. X denotes “tax-favored” consumption and represents an aggregate of consumption goods that are (at least partially) deductible from labor taxes. As discussed in Section 3, these “goods” include (mortgage interest paid on) owner-occupied housing and non-wage compensation such as employer-provided medical insurance. Y denotes an aggregate of consumption goods that do not receive preferential tax treatment.

There is a polluting intermediate good Z (e.g. coal), and a clean intermediate good C , both of which are produced using labor. Household utility is adversely affected by pollution. For now, assume that pollution damages per unit of Z are constant ϕ (this assumption is relaxed later). In addition we assume that production is competitive and characterized by constant returns to scale, therefore supply curves are perfectly elastic.⁴

We represent the tax system by assuming the government levies two taxes on gross labor earnings: a “comprehensive” labor tax t_C and a “non-comprehensive” tax t_N . Expenditure on X is deductible from the non-comprehensive tax but not expenditure on Y . Neither good is deductible from the comprehensive tax.⁵ The government returns all revenues in a lump-sum transfer (G) to the household sector.

The (aggregate) household budget constraint amounts to:

$$(2.1) \quad (1 - t_N)p_X X + p_Y Y = (1 - t_N - t_C)L + G$$

where p_X and p_Y are the producer prices of X and Y which we normalize to unity in the initial equilibrium and L is labor supply. Note that the tax system effectively taxes labor income and subsidizes the consumption of X .

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introduction of a subsidy for one of the two consumption goods in their household and government budget constraints. Thus, we think there is more value added from using a diagrammatic approach in this section, in which the intuition is more transparent, and we relegate the (partially repetitive) mathematical proofs to the Appendix.

⁴ These are standard assumptions. The distortions created by non-competitive market structures are typically not large enough to greatly influence the overall welfare impacts of environmental policies (Oates and Strassmann (1984)). In addition, the assumption of perfectly elastic supply curves seems reasonable for most industries in the long run.

⁵ In practice some components of X , such as non-wage compensation, are deductible from all labor taxation, that is both personal income and payroll taxes. Other components of X , such as mortgage interest, are deductible from income taxes but not payroll taxes. This issue is discussed further in Section 3.

Figure 1 depicts the equilibrium in each of the three distorted markets in the economy. These are the polluting input market (upper panel), the market for tax-favored consumption (middle panel) and the labor market (bottom panel). Demand and supply curves are denoted by “ D ” and “ S ” and initial quantities by subscript 0. MSC^Z denotes the marginal social cost of the polluting input which equals the supply price plus environmental damages per unit. In the labor market the demand curve is perfectly elastic, while the supply curve is upward sloping, reflecting the increasing marginal social cost of labor time.⁶

B. The Welfare Effects of Environmental Policies

Suppose a tax of $\tau = \phi$ is imposed on the polluting input and, for the moment, that the revenue consequences of this policy are neutralized by changing the lump sum transfer. The general equilibrium welfare change from this policy consist of three components (see Appendix A for a proof):

(i) *Pigouvian welfare gain*. Imposing a tax of $\tau = \phi$ on the polluting input reduces the quantity to Z_1 in Figure 1(a). This reduces environmental damages by rectangle $abcd$.⁷ It also produces economic costs of triangle acd , which we call the *primary cost* of the policy. This equals the reduction in consumer surplus (trapezoid acZ_0Z_1), less the reduction in production costs (rectangle dcZ_0Z_1). Environmental benefits less the primary cost leaves the *Pigouvian welfare gain*, equal to the shaded triangle.

(ii) *Subsidy-interaction effect*. In the market for tax-favored consumption there is a wedge of $t_N p^X$ between the supply price (equal to the marginal social cost of X) and the demand price (equal to the marginal social benefit). The environmental tax raises the private costs of producing X and this shifts the supply curve from S_0^X to S_1^X . The demand price increases from $(1 - t_N) p_0^X$ to $(1 - t_N) p_1^X$ and output falls to X_1 . This produces a welfare gain equal to the shaded parallelogram. That is, for each unit reduction in X the reduction in social costs exceeds the reduction in consumer benefits by the wedge between the supply and demand price, $t_N p^X$.⁸ We refer to this welfare effect as the *subsidy-interaction*

⁶ Our assumption of constant returns to scale, and that labor is the only primary input, imply a flat labor demand curve. On the supply curve, a worker well to the left of L_0 has a relatively low opportunity cost to being in the labor force and someone well to the right of L_0 would have a relatively high cost to being in the labor force. The latter may represent, for example, the partner of a working spouse who enjoys looking after the house and children.

⁷ The change in Z is general equilibrium, that is, after the environmental tax revenues have been returned in extra transfers.

⁸ This is a simple application of the familiar formulas for the general equilibrium welfare effect of a new tax in the presence of pre-existing price distortions (see e.g. Harberger (1974), Ch. 2 and 3, and Appendix A below). Note that a new tax causes a second-order welfare effect (i.e. triangle) in the market where it is imposed (in this case the

effect. As explained below, the subsidy-interaction effect is relatively small when the prices of X and Y increase in the same proportion. But becomes empirically important when the relative pollution intensity differs markedly across the X and Y industries.

(iii) *Tax-interaction effect*. The position of the labor supply curve in Figure 1(c) depends on the prices of consumption goods. In particular, the increase in price of X and Y caused by the environmental tax reduces the amount of consumption that can be purchased from a given nominal (net-of-tax) wage. That is, the environmental tax indirectly reduces the return to work effort relative to leisure and this typically causes the labor supply curve to shift upwards (slightly) to S_1^L . Labor supply falls from L_0 to L_1 and this produces a welfare loss equal to the shaded rectangle which has been termed the *tax-interaction effect* (Goulder, 1995a). This rectangle equals the wedge between the gross wage, unity (or value marginal product of labor) and the net wage, $1-t_N-t_C$ (or cost of a unit of foregone leisure) multiplied by the reduction in labor supply.

For the environmental tax with lump-sum replacement these three components constitute the general equilibrium welfare effect of the policy (Appendix A). If instead one of the two labor taxes adjusts to maintain budget balance, an additional welfare effect comes into play.

(iv) *Revenue-recycling effects*. Suppose the net revenue raised by the environmental tax is rectangle *fade* in Figure 1(a).⁹ If this revenue is used to reduce the non-comprehensive tax instead of increasing the lump-sum transfer, this produces two sources of welfare gain. First, this (slightly) raises the net-of-tax wage leading to an increase in labor supply. Second, it also (slightly) reduces the relative subsidy for X and therefore induces a substitution out of tax-favored consumption and into non-tax-favored consumption.¹⁰ The combined welfare gain from these two effects, per dollar of revenue recycled, is denoted MEB^N . This is equivalent to the marginal excess burden (MEB) of non-comprehensive labor taxation, that is the welfare cost from raising an extra dollar of revenue from the non-comprehensive tax

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polluting input market). It causes a first-order effect (a rectangle or parallelogram) in any other market of the economy where quantities change and there is a pre-existing distortion.

⁹ This is somewhat less than the revenue raised in the polluting input market, ϕZ_1 , due to the loss of labor tax revenues in Figure 1(c). The direct revenues from the environmental tax are likely to easily dominate the loss of labor tax revenues, except when environmental taxes approach prohibitive levels (Parry (1995)).

¹⁰ The welfare gain in the labor market is (approximately) equal to the increase in labor supply multiplied by the wedge between the gross and net wage. The welfare gain in the X market equals (approximately) the reduction in X multiplied by the rate of non-comprehensive tax.

(to finance transfer spending). The total welfare gain from using the pollution tax revenues to cut the non-comprehensive labor tax is therefore MEB^N times rectangle *fade*, and we refer to this as the *strong revenue-recycling effect*.

Suppose instead that net revenues are used to reduce the comprehensive labor tax. In this case there is a similar welfare gain in the labor market, but no gain from reducing the subsidy wedge in the market for tax-favored consumption. Therefore (for the same amount of revenues raised) there is a welfare gain of MEB^C times rectangle *fade*, where MEB^C is the MEB for the comprehensive labor tax and $MEB^C < MEB^N$. For this case we say there is a *normal revenue-recycling effect*.¹¹

Emissions Permits

Now suppose the quantity of the polluting input is reduced to Z_1 in Figure 1(a) by issuing the appropriate quantity of pollution permits. This policy induces the same Pigouvian welfare gain as the environmental tax. It also induces an analogous subsidy-interaction effect and tax-interaction effect because it raises the price of the polluting input to the same level $(1+\phi)$. The permit policy creates rents of rectangle ϕZ_1 . If the permits were auctioned the rents would accrue to the government and the welfare effect of the policy would be identical to that of the environmental tax in our model.

Instead, in keeping with practice so far in US pollution control programs, we assume the permits are given out for free to existing firms. Still, the government does (indirectly) receive a minor fraction of the rents because rents are reflected in firm profits (which are subject to corporate income tax) and ultimately non-labor household income (which is subject to personal income tax). Typically this revenue gain is (slightly) less than the reduction in labor tax revenues in our simulation results, so there is no net revenue-recycling effect.

C. Relation to Previous Studies

In previous studies (e.g. Goulder *et al.* (1997), Bovenberg and de Mooij (1994), Parry (1995)) there is no allowance for tax-favored spending and hence no distortion in the X market in Figure 1b.¹² The general equilibrium cost of a revenue-neutral pollution tax in these models therefore consists of the

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¹¹ The tax-interaction effect and normal revenue-recycling effect are familiar from earlier studies. For ease of exposition, we use a slightly different definition here. Other studies (e.g. Parry (1995), Goulder *et al.* (1997)) add on the welfare loss from the reduction in labor tax revenues to the cost of the tax-interaction effect, rather than subtracting it from the revenue-recycling effect, as we have above.

¹² Lawrence Goulder has used a sophisticated dynamic numerical model of the US economy to conduct a number of exercises that examine the effects of environmental taxes (see e.g. Goulder (1995b)). Although it treats the tax system in some detail, it is not disaggregated enough to incorporate tax deductions for medical insurance and mortgage interest.

primary costs, the tax-interaction effect, and the normal revenue-recycling effect. These studies typically find that the tax-interaction effect dominates the (normal) revenue-recycling effect, that is the net impact of environmental tax swaps is to reduce labor supply and increase the costs of pre-existing taxes. These studies therefore cast doubt on the “double dividend” hypothesis, that is the claim that an environmental tax could both improve the environment and reduce the costs of the tax system at the same time.¹³

Our numerical results below differ from those in these earlier studies to the extent that the strong and normal revenue-recycling effects differ and, to a lesser extent, because of the subsidy-interaction effect. The ratio of the strong to the normal revenue-recycling effect equals MEB^N/MEB^C . In Appendix B we derive the following formula for MEB^N (when $\tau = 0$ and we ignore feedback effects on the environment):

$$(2.2) \quad MEB^N = \frac{\frac{t}{1-t} \varepsilon_L^H + \frac{t_N}{1-t_N} s_X \eta_X^H}{1 - \frac{t}{1-t} \varepsilon_L^M - s_X \left\{ 1 + \frac{t_N}{1-t_N} \eta_X^M \right\}}$$

where ε_L^M and ε_L^H are the uncompensated (Marshallian) and compensated (Hicksian) labor supply elasticities, η_X^M and η_X^H are the uncompensated and compensated own price elasticity of demand for tax-favored consumption (expressed as positive numbers), s_X is the share of tax-favored consumption in total consumption and $t = t_C + t_N$ is the total labor tax wedge. Setting $t_N = 0$ gives:

$$(2.3) \quad MEB^C \cong \frac{\frac{t}{1-t} \varepsilon_L^H}{1 - \frac{t}{1-t} \varepsilon_L^M}$$

The formula in (2.3) has been discussed at length in other studies (see e.g. Browning (1987) and Snow and Warren (1996)) and we do not go into details here.¹⁴ For our purposes the key point here is that

¹³ This hypothesis stems from earlier analyses that essentially “tack on” the revenue-recycling effect to a partial equilibrium analysis of environmental taxes. Since they are not general equilibrium, these analyses fail to capture the crucial tax-interaction effect.

¹⁴ These formulas are for an increase in labor taxation to finance an extra dollar of the lump-sum transfer. If the extra revenue were not returned to households (for example it went out of the economy in foreign aid) all the elasticities would be uncompensated, while if the extra public spending was sufficient to keep household utility constant all the elasticities would be compensated. In our case the formulas depend on both uncompensated and compensated elasticities because the extra revenue to be recycled from an incremental increase in labor tax ($L + t dL/dt$ in the case of (2.3)) does not fully compensate households for the loss in surplus from the tax increase (L). The formula in (2.3) is exact when $t_N = 0$, as in previous studies. The MEB for the comprehensive tax in our model is a little more complicated due to a cross-price effect in the X market, however in quantitative terms the difference is very small.

(comparing (2.2) and (2.3)) the increase in the MEB because of tax-favored consumption depends on three key parameters, which we discuss below: the relative size of the tax-favored sector, the (compensated and uncompensated) demand elasticity for tax-favored consumption, and the subsidy wedge.

3. Numerically-Solved Model

We now develop a numerical model to compare, quantitatively, the welfare impacts of alternative environmental policies. Subsections *A* and *B* describe the assumed functional forms and model calibration. We consider “low”, “medium” and “high” scenarios for the costs of pre-existing taxes.

A. Functional Forms

The household has the following constant elasticity of substitution (CES) form for utility:

$$(3.1) \quad U = \left\{ \alpha_U C^{\frac{\sigma_U-1}{\sigma_U}} + (1-\alpha_U)(\bar{L}-L)^{\frac{\sigma_U-1}{\sigma_U}} \right\}^{\frac{\sigma_U}{\sigma_U-1}} - \phi(Z)$$

$$(3.2) \quad C = \left\{ \alpha_C X^{\frac{\sigma_C-1}{\sigma_C}} + (1-\alpha_C)Y^{\frac{\sigma_C-1}{\sigma_C}} \right\}^{\frac{\sigma_C}{\sigma_C-1}}$$

where C denotes composite consumption or sub-utility from the consumption of goods and the σ 's and α 's are parameters. σ_U and σ_C denote the elasticities of substitution between composite consumption and leisure, and between individual consumption goods, respectively. The α 's are share parameters. $\phi(\cdot)$ is disutility from the pollution caused by the dirty input Z , where $\phi > 0$, $\phi' \geq 0$.

There are three notable restrictions embedded in this utility function—Section 5 discusses when it might be appropriate to relax these assumptions and how this would affect the results. First, the separability assumption in (3.1) simplifies our analysis by ruling out possible feedback effects of changes in environmental quality on the labor/leisure decision and the choice among consumption goods. Second, the weak separability between leisure and consumption goods, and the homothetic property of the function in (3.2), together imply that X and Y are equal substitutes for leisure (Deaton (1981)). This seems a reasonable benchmark assumption, given that we know of no evidence to suggest that the degree of substitution between tax-deductible consumption and leisure is significantly stronger or weaker than the degree of substitution between other consumption goods and leisure. Third, we do not further

disaggregate consumption goods into those that are produced by relatively clean and relatively dirty industries.¹⁵

X and Y are produced using the polluting intermediate good (Z), a clean intermediate good (H), and labor, according to the following CES production functions:

$$(3.3) \quad X = X \left\{ \alpha_D^X Z_X^{\frac{\sigma_X-1}{\sigma_X}} + \alpha_C^X C_X^{\frac{\sigma_X-1}{\sigma_X}} + \alpha_L^X L_X^{\frac{\sigma_X-1}{\sigma_X}} \right\}^{\frac{\sigma_X}{\sigma_X-1}}$$

$$Y = Y \left\{ \alpha_D^Y Z_Y^{\frac{\sigma_Y-1}{\sigma_Y}} + \alpha_C^Y C_Y^{\frac{\sigma_Y-1}{\sigma_Y}} + \alpha_L^Y L_Y^{\frac{\sigma_Y-1}{\sigma_Y}} \right\}^{\frac{\sigma_Y}{\sigma_Y-1}}$$

where σ_X and σ_Y are the elasticity of substitution between inputs in the two industries and the α 's are input share parameters, and

$$(3.4) \quad Z = Z^X + Z^Y; \quad H = H^X + H^Y$$

Pollution is proportional to Z , but we relax this assumption later.

Labor is the only input used to produce Z and H and the marginal product of labor in each of these intermediate goods industries is taken to be constant and normalized to unity. Thus:

$$(3.5) \quad Z = L^Z; \quad H = L^H$$

Labor market equilibrium requires:

$$(3.6) \quad L^X + L^Y + L^Z + L^H = L$$

That is, labor demanded by final and intermediate good industries equals labor supplied by households.

As discussed above, the government provides a lump-sum transfer (G), levies a comprehensive tax (t_C) and non-comprehensive tax (t_N) on labor income, and reduces Z either by a pollution tax (τ) or pollution permits. We assume the government budget must balance. In the case of the pollution tax this constraint is:

$$(3.7) \quad G = (t_C + t_N)L - t_N p_X X + \tau Z$$

That is, government spending equals labor tax revenues less deductions plus pollution tax revenue.

Households choose X , Y , and L to maximize utility subject to the budget constraint given by (2.1). This generates the demand functions for goods and the labor supply function. Firms choose inputs to minimize production costs and this determines costs per unit of output, or producer prices. In equilibrium

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¹⁵ Of course, it may be appropriate to revise these central case assumptions somewhat in the light of future econometric investigations. At any rate, we have to make some assumptions in order to estimate the costs of environmental policies, and we believe our benchmark assumptions provide the most logical starting point.

demand and supply are equated in the final goods, intermediate goods, and labor markets, and the household and government budget constraints are satisfied.¹⁶

B. Model Calibration

The consumption/leisure substitution elasticity (σ_l) is calibrated to be consistent with estimates of labor supply elasticities. The econometric evidence on labor supply elasticities has been reviewed many times and we do not go into the details here (see e.g. Killingsworth (1983)). For our purposes there are several important points. First, for our highly aggregated model the labor supply response to changes in net wages represents the impact on average hours worked per employee and the impact on the participation rate, averaged across all members (male and female) of the labor force. Second, there is still a fair amount of uncertainty over the economy-wide labor supply elasticity, and therefore it prudent to consider a range of values. Third, our model should be consistent with estimates for both the compensated and uncompensated labor supply elasticity. In our medium scenario for the MEB of pre-existing taxes, we choose the consumption/leisure elasticity and the initial ratio of labor supply to the time endowment to imply an uncompensated and a compensated labor supply elasticity of 0.15 and 0.4 respectively. These are typical values used in previous studies of environmental policies (e.g. Goulder *et al.* (1997)). In our low and high MEB scenarios we use values of 0.1 and 0.25 for the uncompensated and 0.3 and 0.5 for the compensated elasticity, respectively.¹⁷ Following other studies (Lucas (1990), Goulder *et al.* (1997)), we assume a marginal tax wedge in the labor market of 40 percent, which reflects the combined effects of personal, payroll and sales taxes.

Table 1 shows estimates of federal revenue losses (or tax expenditures) for various categories due to deductions and exemptions built into the income tax system for 1995. The two largest components of tax-favored spending are employer provided medical insurance and homeowner mortgage interest. Spending on these goods amounted to about 6 percent and 5 percent respectively, of gross labor income in 1995.¹⁸ There are a variety of other quantifiable items (e.g. deductions for child care and employee parking) that add about another 1.6 percent. In addition, there are other categories that are difficult to measure, such as business lunches and trips, employer-provided health clubs, debt-financed spending

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¹⁶ We used GAMS with MPSGE to solve the model.

¹⁷ These values are roughly consistent with a recent survey of opinion among labor economists by Fuchs *et al.* (1998), assuming a weight of 0.6 and 0.4 for the male and female elasticities reported in their Table 2.

¹⁸ Direct estimates of these items overstate tax-favored spending, for example mortgage payments include repayment of principal, which is not tax-deductible. They also reflect payments of all taxpayers, including those that do not itemize deductions, and therefore do not receive the tax subsidy. Total health care expenditures include those for seniors who are not in the labor force.

secured by real estate, and so on. In short, it is tricky to pin down really accurately the relative size of the tax-favored consumption sector. We assume $s_X = 0.11, 0.13$ and 0.15 in our low, medium, and high MEB scenarios, respectively.¹⁹

We exclude from our analysis a variety of other tax expenditures, shown in the lower half of Table 1. These include deductions for savings and investment—pension contributions, interest on state and local bonds, capital gains at death, corporate income tax deductions, and interest on life insurance savings. To incorporate these deductions would require a dynamic model with investment in different types of assets that are taxed or subsidized at different rates, and is beyond the scope of this paper. Deductions for state and local income taxes affect the overall level of labor taxation—and this is implicitly taken into account in our estimates of labor tax rates—but do not distort the allocation of consumption expenditures. We also exclude charitable contributions, implicitly assuming that there are external benefits that just offset the tax-subsidy at the margin. Finally, property taxes and (to some extent) capital gains taxes on home sales, can be deducted from income taxes. These provisions affect the size of the price distortion in the housing sector, but not the share of housing services in labor income.

If all tax-favored consumption were fully deductible from labor taxes, the subsidy wedge in the market for tax-favored consumption would be 40 percent in our model. This is not quite the case however, and we assume a subsidy of 30 percent.²⁰ As discussed in Section 5, we abstract from a number of other complications that affect the overall size of the subsidy wedge.

The overall demand elasticities for tax-favored consumption depend on the elasticity of substitution between tax-deductible consumption and other consumption goods, and s_X , as follows:

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¹⁹ At first glance it might seem that tax-favored consumption should also include black market activities where cash transactions are not reported as taxable income (possible examples include the hiring of nannies and gardeners). However since these activities are not observed they are implicitly counted as leisure activities, and hence are captured in studies that estimate how taxes affect the substitution from observed labor supply into leisure.

²⁰ In particular mortgage interest is only deductible from the personal income tax, and not the payroll tax. It is subsidized at the marginal rate of income tax (averaged across individuals) which is around 25 percent. Our assumptions about tax rates and s_X imply government revenue is 34–37 percent of total spending in our benchmark, which is approximately consistent with the ratio of total tax receipts to net national product. Note that our strong revenue-recycling effect implicitly assumes that environmental tax revenues are used to cut the rate of personal income tax. The revenue-recycling effect would be somewhat smaller if revenues were used to cut the payroll tax, since this tax has fewer deductions.

Certain sector-specific tax provisions further complicate the wedge between the demand and supply price in the housing market. In particular, property taxes are levied on the value of the housing stock. However differences in average property tax rates between jurisdictions are reflected in differences in the value of local services. To this extent, property taxes act like a user fee and are not distortionary. Moreover, a quarter of the property tax liability is essentially nullified by the deductibility from income taxes.

$\eta_X^M = (1 - s_X)\sigma_C + s_X$ and $\eta_X^H = (1 - s_X)\sigma_C$.²¹ Various studies have estimated demand elasticities for individual components of X . For example, in a careful study Rosen (1979) estimated the (uncompensated) demand elasticity for home mortgages to be unity. A recent estimate of the demand elasticity for health insurance is 1.8 (Gruber and Poterba (1994)).²² We choose σ_C to imply values of 1, 1.2 and 1.4 for the uncompensated demand elasticity for X in our low, medium and high MEB scenarios.

Table 2 summarizes our key parameter values. They imply an MEB from the non-comprehensive tax equal to 0.31, 0.46 and 0.56 in the low, medium and high scenarios. In earlier studies that neglect tax-favored consumption (e.g. Goulder *et al.* (1997)) the MEB is around 0.3, which equals our MEB for the comprehensive tax in the medium scenario. At first glance it may seem surprising that the presence of tax-favored consumption increases the MEB so much, when tax-favored consumption is only around 13 percent of the size of the labor market. However, this is counteracted to some extent because tax-favored consumption is much more sensitive to changes in tax rates than labor supply.²³

Our estimates of the MEB with tax deductions are approximately consistent with those recently obtained by Parry (1999a) in a more detailed study, and we refer the reader to this paper for more discussion about underlying parameter values. However they are well below estimates of the MEB in Feldstein (1998)'s seminal article, which were typically above unity. To calculate the MEB, Feldstein used estimates of the elasticity of people's taxable income with respect to changes in income tax rates. This elasticity reflects substitution effects into all of the tax deductions listed in Table 1. As discussed above, for our analysis it is appropriate to exclude many of these categories—in fact over 60 percent of them—although the deductions for investment and savings would be relevant for a dynamic analysis.²⁴

We take the elasticities of substitution in the X and Y industries (σ_X and σ_Y) to be unity. This is a standard assumption and, as discussed below, our results are not sensitive to other values. In our initial simulations the factor input ratios are initially the same in both consumption goods industries, but this is relaxed later on. Finally, we assume the initial value of output in each intermediate good industry amounts

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²¹ These formulas can be obtained after differentiating the expenditure and indirect utility functions for CES utility functions (see Varian (1984), pp. 130), and some manipulation.

²² Earlier studies typically find significantly lower estimates, however Gruber and Poterba suggest that these studies contain a number of methodological problems.

²³ In terms of our MEB formulas, the extra terms in (2.2) compared with (2.3) are still significant because, even though s_X is small, the η 's are much larger than the ε 's.

²⁴ Moreover, the most recent estimates of the taxable income elasticity are significantly lower than those used in Feldstein's original analysis (see Carroll, 1998).

to 10 percent of the value of total final output. The relative costs of environmental policies are not especially sensitive to alternative assumptions about the size of the polluting sector in GDP.²⁵

4. Results

This section presents our simulation results illustrating how the tax system affects the costs, overall welfare impacts, and optimal levels of environmental policies.

A. Marginal Costs

In Figure 2 we compare the marginal cost of reducing pollution under alternative policy instruments up to 50 percent below pre-regulation levels. Marginal costs are expressed as a percent of the initial value product of the polluting input. For this figure we mainly focus on qualitative results, and since these are essentially the same under all three MEB scenarios, we just illustrate the medium MEB case.

MC^{PRIM} indicates marginal costs in a first-best case when we set pre-existing taxes and the subsidy to zero. This curve reflects primary costs only and is the same under both the pollution tax and pollution permits.²⁶ MC^{PRIM} has a zero intercept, and is upward sloping, reflecting the increasing marginal cost of substituting other inputs for the polluting input in production and the increasing marginal cost of reducing the amount of consumption.

MC^{SI} shows marginal costs when we allow for the 30 percent subsidy for X , but still set labor taxes at zero.²⁷ The difference between this curve and MC^{PRIM} reflects the (marginal) subsidy-interaction effect. This effect is a welfare gain (the parallelogram in Figure 1(b)) because the pollution tax reduces the output of X , thus offsetting to some extent the distortionary effect of the subsidy. However, in practical terms the subsidy-interaction effect is negligible. This is because the price of X and Y increase in the same proportion, and hence the reduction in X reflects substitution into leisure only and not into other consumption. Subsequent simulations show, however, that the subsidy-interaction effect can be important

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²⁵ That is, primary costs and the tax-interaction and revenue-recycling effects increase in roughly the same proportion as the size of the polluting sector increases, leaving relative costs unaffected (Goulder *et al.* (1997).

²⁶ To calculate the primary costs we re-calibrate the distribution parameters such that the initial quantity of goods and leisure are the same as in the model with non-zero taxes. However the substitution elasticity parameters, which crucially determine the relative costs of policies, are the same across the models with and without the labor taxes. Pollution tax revenues are returned lump sum.

²⁷ For this case the pre-existing subsidy is financed by a lump-sum tax.

when the relative pollution intensity differs significantly between the tax-favored and non-tax-favored production sectors.

MC^{LS} indicates marginal cost under the pollution tax with both labor taxes but with no revenue-recycling effect; that is, environmental tax revenues are neutralized by adjusting the lump-sum transfer. The difference between this curve and MC^{SI} reflects the (marginal) tax-interaction effect. This effect causes a substantial upward shift of the marginal cost curve (see Goulder *et al.* (1997) and Parry (1997) for more discussion).

MC^{COM} shows marginal costs under the pollution tax with revenues used to reduce the comprehensive tax (holding government transfers constant in real terms). It equals MC^{LS} less the (marginal) benefit from the normal revenue-recycling effect. Comparing MC^{COM} with MC^{SI} we can infer that the tax-interaction effect dominates the normal revenue-recycling effect at the margin (except at zero pollution reduction). Again, this result is familiar from other studies (Goulder *et al.* (1997), Parry (1995)). The gap between MC^{LS} and MC^{COM} decreases with the amount of pollution reduction, since the erosion of the pollution tax base reduces the marginal revenue-recycling effect. Indeed the marginal revenue-recycling effect eventually becomes negative if pollution is reduced by more than a certain amount. Beyond this point the pollution tax Laffer curve is downward sloping and MC^{COM} rises above MC^{LS} .

Finally, MC^{NC} is the marginal cost curve for the pollution tax with revenues used to reduce the non-comprehensive labor tax.²⁸ This curve equals MC^{LS} less the (marginal) benefit from the strong revenue-recycling effect. It has a negative intercept and marginal costs are negative up to a pollution reduction of 13 percent in our medium cost scenario. Thus, even if there were no environmental benefits it would still be optimal to reduce pollution by 13 percent in this case. Up to a point therefore, the environmental tax swap reduces the overall costs of the tax system, not counting environmental benefits. It makes the tax system more efficient by effectively reducing the net subsidy for tax-favored consumption.²⁹ On the other hand, the environmental tax is more distortionary than the labor tax in the sense that it excludes non-polluting inputs from the tax base. At least for more modest levels of pollution tax, the advantage from the former effect outweighs the disadvantage from the latter effect.

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²⁸ To avoid cluttering Figure 2, we omit marginal costs for emissions permits in the presence of pre-existing taxes. The effects of this policy are explained below.

²⁹ If there were no tax deductions in our model (and no environmental effects), the labor tax would always be more efficient than the pollution tax for raising revenues, under our benchmark assumptions.

B. Total Costs

Figure 3 shows the total (as opposed to marginal) costs of reducing pollution under various policies, expressed relative to the total primary costs. When a cost curve lies above (below) unity, the net impact of the tax system is to raise (lower) the overall cost of a policy above (below) its primary costs.

The most novel feature of Figure 3 is the total cost curves for the pollution tax with revenues used to reduce the non-comprehensive labor tax. The thicker curve, denoted TC^{NC} , indicates the medium MEB scenario, and the upper and lower dotted curves correspond to the low and high MEB scenarios (or low and high substitution elasticities in the utility function), respectively. These curves lie below the horizontal axis for pollution reductions up to between 19 and 33 percent. When total costs are negative the welfare gain from reducing the costs of the tax system more than offset the primary cost of the policy. Goulder (1995a) refers to this as a “strong” double dividend from environmental taxes. When total costs are positive but less than unity, there is still a net welfare gain from interactions with the tax system. This is referred to as an “intermediate” form of the double dividend in Goulder (1995a). For example in the medium MEB scenario, if the reduction in pollution is below 50 percent, interactions with the tax system reduce the overall costs of the pollution tax by over 50 percent.³⁰

In contrast, if revenues are instead used to reduce the comprehensive labor tax total costs are indicated by TC^{COM} in the medium cost scenario. In this case there is no potential for a double dividend; the general equilibrium costs of this policy exceed the primary costs by around 11 percent.³¹ Figure 3 clearly shows that—by neglecting the welfare gain from the reduced subsidy for tax-favored consumption—previous studies may dramatically overstate not only the magnitude of costs from environmental tax swaps, but also the sign of the welfare change. For example, for a pollution reduction of 20 percent in the medium MEB scenario, previous studies would estimate costs equal to 111 percent of primary costs; in contrast our analysis predicts a welfare *gain* equal to 40 percent of primary costs.

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³⁰ Thus, for more modest levels of pollution taxation there is potential for a sizable double dividend, but this declines at higher levels of pollution taxation. The reason for this is clear from Figure 1. At modest levels of pollution taxation, the net revenues raised, and hence the (strong) revenue-recycling effect, are large relative to the primary cost triangle *acd*. But at high levels of pollution taxation the base of the tax is much smaller, and this reduces the size of the strong revenue-recycling effect relative to primary costs. At 100 percent pollution reduction there are no revenues raised under any policies, and the total costs of all the policy instruments we consider become equal, and exceed primary costs.

³¹ Previous studies (Goulder *et al.* (1997), Parry (1997)) find somewhat higher cost ratios for this policy. This is because they use slightly different definitions to compare welfare differences between first-best and second-best outcomes. The difference between the TC^{NC} and TC^{COM} curves in Figure 3 is a little larger than can be explained by the difference between the strong and normal revenue recycling effects alone. The reason is a little technical. When the recycling of pollution tax revenues reduces the subsidy distortion for tax-favored consumption this raises the relative attractiveness of work effort to leisure at the margin. As a result the overall reduction in labor supply is slightly smaller when there is a strong rather than a normal revenue-recycling effect (in fact the overall change in labor supply is slightly positive for modest pollution reductions).

When the revenue effects of environmental taxes are neutralized by lump-sum transfers, total costs are given by TC^{LS} in the medium MEB case. The overall costs of this policy are infinitely larger than the primary costs for an incremental amount of pollution reduction. This reflects the positive intercept of the marginal cost curve for this policy in Figure 2. As the extent of pollution reduction increases, total costs fall relative to the primary cost. This is because the primary cost triangle acd in Figure 1(a) increases relative to the cost of the tax-interaction effect, the shaded rectangle (for more discussion see Goulder *et al.* (1997)). Finally, TC^{PER} is the (general equilibrium) total cost of reducing pollution by emissions permits, relative to the primary cost, when government budget balance is maintained by adjusting the comprehensive labor tax. Although we assume that 40 percent of permit rents accrue to the government in tax revenue, this is not quite enough to compensate for the reduction in labor tax revenues, hence tax rates must be increased slightly to maintain government budget balance and TC^{PER} lies above TC^{LS} .³²

Previous studies have emphasized the potentially strong efficiency case for using (revenue-neutral) pollution taxes—or equivalently in our analysis, auctioned emissions permits—over non-auctioned emissions permits (see e.g. Parry (1997), Goulder *et al.* (1997), Parry *et al.* (1999)). This case is based on a comparison of total cost curves that (roughly speaking) correspond to TC^{COM} and TC^{PER} in Figure 3. However, when recycling the revenues from the pollution tax or permit sales produces a welfare gain in the market for tax-favored consumption, in addition to the welfare gain in the labor market, the appropriate comparison is between the TC^{NC} curves and (approximately) TC^{PER} in Figure 3. In this case, the efficiency cost savings from using the pollution tax or auctioned permits over free pollution permits is potentially much more dramatic. For example, if pollution is reduced by 20 percent, the cost of emissions permits is more than 300 percent of primary costs; in contrast the pollution tax or auctioned permits produces an economic gain equal to about 40 percent of primary costs in the medium MEB scenario. As consistent with earlier studies, however, the cost saving from using the pollution tax over emissions permits is relatively less dramatic at higher levels of pollution reduction.

C. Relative Pollution Intensities

We now relax the assumption of equal pollution intensities in the tax-favored and non-tax-favored production sectors. This affects the costs of policies by changing the relative size of the subsidy-interaction effect. Along the horizontal axis in Figure 4 we vary the (initial) ratio of the polluting input to the clean input in the tax-favored sector, relative to the same ratio in the non-tax-favored sector (keeping

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³² If the non-comprehensive tax is adjusted to maintain budget balance, total costs are slightly higher than indicated by TC^{PER} .

the total amount of pollution the same). This ratio is less (greater) than unity when tax-favored consumption is cleaner (more polluting) than non-tax-favored consumption.

The TC^{SI} curve shows the total costs of reducing pollution by 10 percent in the medium MEB case, expressed relative to the primary costs, when there is a 30 percent subsidy for X but labor taxes are zero. The gap between this curve and unity isolates the subsidy-interaction effect. As the relative pollution intensity in the tax-favored sector falls (moving left along the horizontal axis), the welfare gain from the subsidy interaction effect declines, and becomes negative (this occurs when TC^{SI} curve rises above unity and the pollution intensity ratio is less than .57). This is because the pollution tax drives up the price of non-tax-favored consumption by a proportionally greater amount, hence reducing, and eventually reversing the direction of, the change in tax-favored consumption.

The TC^{NC} curve shows the total costs of the pollution tax with the strong revenue-recycling effect relative to primary costs, for a 10 percent pollution reduction (again the upper and lower dotted curves correspond to the low and high MEB scenarios respectively). As the relative pollution intensity of tax-favored consumption falls, the costs of this policy increase as the subsidy-interaction effect declines and becomes negative. In fact, when the intensity ratio falls below .60, .35, or .10 in the low, medium and high MEB scenarios, total costs are positive, hence the strong double dividend disappears.

Thus our results are sensitive to the relative pollution intensity of the tax-favored sector. Even the intermediate form of the double dividend disappears in the limiting case when polluting inputs are used exclusively in the non-tax-favored sector. Moreover if non-auctioned emissions permits were used to reduce these pollutants the general equilibrium costs (relative to primary costs) would be substantially higher than implied by figure 3, since these policies serve to exacerbate the distortion in prices between the tax-favored and non-tax-favored sectors. Having said this, even if the tax-favored sector is relatively less polluting, it is still possible to generate a significant double dividend for modest levels of pollution taxes. For example, when the pollution intensity in the tax-favored sector is only 50 percent of that for the rest of the economy, a revenue-neutral tax that reduces pollution by 10 percent produces a net economic gain equal to 40 percent of primary costs in our medium MEB scenario.

Some pollutants—e.g. chemical pesticides and fertilizers used in agricultural production—are used exclusively in the non-tax-favored sector, and environmental taxes on these pollutants would not yield the double dividend in our analysis. However, pollutants associated with energy production may, if anything, be used more intensively in the tax-favored sector. This is because the housing sector is responsible for a disproportionate amount of energy consumption. At any rate, estimating the relative

intensity of use for different pollutants in the tax-favored sectors would be a useful topic for future research.³³

D. Welfare under the Pigouvian Rule

In Figure 5 we compare the overall welfare impacts of the different environmental policies (i.e. environmental benefits minus economic costs), sticking, for simplicity, with the medium MEB scenario and equal pollution intensities across sectors. We postulate different values for the marginal environmental benefit from reducing pollution, and the corresponding Pigouvian pollution reduction is shown along the horizontal axis.³⁴ The vertical axis shows the ratio of the general equilibrium welfare gains from this pollution reduction to the Pigouvian welfare gain (i.e. the shaded triangle in Figure 1(a)).

Again, the novel feature from this figure is the curve for the pollution tax with the strong revenue-recycling effect, W^{NC} . This curve lies above unity, while the curves for all the other policies lie below unity. That is, the general equilibrium welfare gain is higher than the Pigouvian welfare gain for this policy, and less for all other policies. Previous studies find that, even with the (normal) revenue-recycling effect, the welfare gain from Pigouvian pollution policies is typically somewhat less than the Pigouvian welfare gain. In contrast, the welfare gain from the pollution tax with strong revenue recycling is more than double the Pigouvian welfare gain for pollution reductions below 25 percent. Finally, we note again the potentially striking difference between policies that do and do not produce the (strong) revenue-recycling effect. For pollution reductions below 25 percent a pollution tax with lump-sum replacement *reduces* welfare, despite environmental benefits.

E. Optimal Policies

Our final diagram, Figure 6, shows the second-best optimal pollution reduction under alternative policies, expressed relative to the optimal Pigouvian pollution reduction (for the medium MEB scenario and alternative assumptions about marginal environmental benefits). When these curves lie above (below) unity the optimal (second-best) pollution reduction is greater (less) than would be implied by a partial equilibrium analysis. As consistent with our earlier results, the optimal levels of policies differ

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³³ Such estimation can become quite involved and is really beyond the scope of this paper. For example, measuring the relative energy intensity of tax-favored consumption would require estimating energy costs as a fraction of the value of health and housing output, taking account of energy used in the upstream production of all intermediate inputs used by these industries. It would also require estimating to what extent extra spending on housing translates into more energy demand for space heating and cooling, lighting, and so on.

³⁴ That is, the pollution reduction from imposing a tax equal to marginal environmental benefits. Marginal benefits are taken as constant, which seems a reasonable approximation for some pollutants, such as sulfur and carbon (see Burtraw *et al.* (1997) and Pizer (1997)).

substantially when (marginal) environmental benefits are more modest relative to (marginal) primary costs. For example when environmental benefits imply the optimal Pigouvian (or partial equilibrium) pollution reduction is 15 percent, in a general equilibrium analysis this would be zero under the tax with lump-sum replacement, 13.5 percent under the tax with normal revenue recycling, and 22.5 percent under the tax with strong revenue recycling.

F. Further Sensitivity Analysis

Previous studies (e.g. Goulder *et al.* (1997), Parry (1997)) have found that—for a given reduction in pollution—the size of the tax-interaction and revenue-recycling effects relative to the partial equilibrium costs of environmental policies are not really affected by changing the degree of substitution between pollution and other inputs. In other words these three effects are all reduced in roughly the same proportion, leaving the relative total cost curves in Figure 3 unaffected.³⁵ We find the same result in our analysis. Similarly, increasing the possibilities for substitution by allowing for end-of-pipe treatment does not have much effect on relative costs.³⁶

5. Further Discussion

In this section we comment on how the results would be affected by various extensions to the analysis (for more discussion of some of these issues see e.g. Bovenberg and Goulder (1998), Parry (1999b)).

Non-separable environmental effects. Our assumption that environmental quality is separable in the utility function implies that changes in environmental quality do not have feedback effects on current labor supply decisions, or the choice among consumption goods. This seems plausible for some cases. For example, when the environmental impacts of current emissions do not occur for several decades (climate change, nuclear waste), or when pollution affects ecological rather than economic variables.

But there are some notable counter-examples. Reducing work-related traffic congestion may produce a positive feedback effect on labor supply, by reducing the time costs of commuting. Cleaner air

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³⁵ We can see this from Figure 1. Suppose that we pivot the D^Z curve about point c such that it now intersects the vertical line at Z_1 halfway between points a and d . This halves the primary cost of reducing pollution from Z_0 to Z_1 . But it will also halve the tax required to reduce the polluting input to Z_1 , and hence halve the revenue-recycling effect. Similarly, this will roughly halve the effect of the tax on product prices, and hence the tax-interaction effect.

³⁶ We expanded our model to allow firms to reduce emissions per unit of the dirty good by employing labor, such that the primary costs of reducing pollution by 10 percent were halved. The ratio of the general equilibrium costs to primary costs under the emissions tax with the strong revenue-recycling effect fell from -1.90 to -1.85 .

improves human health and this may have feedback effects on the demand for health care and labor supply.³⁷ On the other hand, a more pleasant environment (beaches, national parks, etc.) may increase the value of leisure pursuits relative to work time. A fruitful area for future research would be to explore empirically to what extent these sorts of feedback effects could dampen or magnify the tax interactions discussed above.

Substitution between polluting goods and leisure. Implicitly, we have assumed that goods produced by relatively clean and relatively polluting industries have the same degree of substitution with leisure. If pollution is concentrated in industries that are relatively weak (strong) leisure substitutes the tax-interaction effect is smaller (larger) (see e.g. Bovenberg and Goulder (1998), Parry (1995)). Yet many pollutants are associated with energy production, and to our knowledge there is not clear evidence that energy-intensive goods as a group are either significantly weaker, or significantly stronger, leisure substitutes than consumption goods as a whole. However, there are some special cases where incorporating relatively weak leisure substitutes would be important. These include externalities associated with necessity goods, such as smoke from cigarettes, and pollutants associated with agricultural production.

Parry (1995) shows that the tax-interaction effect³⁸ is (approximately) proportional to the price elasticity of the polluting good with respect to leisure divided by the price elasticity for aggregate consumption with respect to leisure. Thus, if the cross price elasticity for cigarettes was, say, 40 percent of that for consumption goods as a whole, the tax-interaction effect for cigarettes would be 60 percent lower than in our benchmark simulations.³⁹

Substitution between tax-favored goods and leisure. The preference structure in (3.1) and (3.2) implies that tax-favored goods and non-tax-favored goods exhibit the same degree of substitution with leisure (Deaton, 1981). Suppose we relax the assumption of unitary income elasticities implied by the homothetic functional form in (3.2). This alters the strong revenue-recycling effect, but only very slightly—if we

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³⁷ The direction of the health feedback effects is unclear, however. For example, if older people live longer due to better health, medical expenditures over their lifetime could still increase. Similarly Williams (1998) finds that the labor supply effects of improved health are ambiguous.

³⁸ In his terminology this is the “interdependency effect”.

³⁹ A value for the ratio of cross price elasticities might be obtained without doing a detailed econometric study. If we maintain the assumption of weak separability between consumption and leisure (which is reasonable in some cases), but allow for non-homothetic preferences, then from Deaton (1981) we know that the elasticity ratio is equal to the income elasticity of demand for the polluting good.

keep the model consistent with evidence on the uncompensated price elasticity.⁴⁰ However, suppose that we relax the assumption of weak separability between consumption goods and leisure in (3.1). If people obtain better housing at the expense of other consumption goods if anything this is likely to increase rather than decrease the value of leisure time relative to labor time. Thus, since the environmental tax with the strong revenue-recycling effect reduces the relative consumption of tax-favored consumption, this could produce an additional efficiency gain through a positive feedback effect on labor supply. In this respect, our results on the welfare effects of this policy may be conservative.

Capital. In principle, another useful extension would be to introduce capital as a second factor input. This would require a considerably more complex dynamic analysis in which the taxation of capital distorts the choice between current and future consumption, in addition to the choice between tax-favored assets and other capital assets.⁴¹ In this setting the welfare gain from revenue-neutral environmental taxes may be significantly larger than in our static analysis, though this will depend on the relative pollution intensity of tax-favored capital goods.

Non-tax distortions in the housing and health markets. The size of the subsidy wedge for tax-favored consumption (the height of the parallelogram in Figure 1(b)) is much more complicated in practice than we have assumed. There may be efficiency gains from this subsidy, for example it may offset market failures due to asymmetric information in health insurance, and positive externalities to neighbors if houses are better maintained when owned rather than rented. In addition, there are a variety of regulations that raise the price of tax-favored consumption goods. These include building codes, rent controls, and zoning restrictions in the housing market, and occupational licensing and drug regulations in the health market. All of these effects reduce the overall wedge between the marginal social cost and marginal social benefit from tax-favored consumption. However what matters is the impact on the price of tax-favored goods relative to non-tax-favored goods—the price effect will tend to be offset to the extent that other regulations raise the relative price of non-tax-favored goods.

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⁴⁰ If we keep the same value for the uncompensated own price elasticity of demand for tax-favored consumption, then through the Slutsky equation, changing the income elasticity implies different values for the compensated price elasticity η_X^H in (2.2). If the income elasticity is between 0 and 2 (and evidence suggests it is closer to unity than either of these values), then η_X^H varies between .94 and 1.2 in our medium MEB scenario. This implies values for MEB^N of between 0.45 and 0.47.

⁴¹ Note, however, that at least in terms of size the labor market is easily the more important market. It accounts for about 70 percent of total factor income in the United States.

Unfortunately, the quantitative importance of these factors is often difficult to pin down (see e.g. Rosen (1985), Pauly (1986)). Moreover, there are other factors that operate in the opposing direction. For example, housing receives additional subsidies because imputed income is not subject to tax, low-income households receive public assistance, and complementary services such as roads and schools are usually subsidized. Government programs subsidize health care for the poor and elderly. Also, these goods may confer some negative externalities, such as habitat destruction and congestion caused by housing development, and the crowding out of lower income workers from the health insurance market as prices rise in response to demand for higher quality from the better off. In short it is difficult to assess whether on balance these additional factors would increase or reduce the overall subsidy wedge for tax-favored consumption, let alone by how much.

Other tax deductions. A key theme of this paper is that the presence of tax expenditures, when significant relative to total labor tax revenues, can substantially raise the efficiency gains from recycling environmental tax revenues in income tax reductions. However there are a variety of other tax expenditures that—although small in size—could still significantly affect the welfare impact of environmental policies, if they apply directly to the market that is being regulated. Some examples might include favorable depletion allowances for petroleum and other minerals, favorable capital gains treatment for farm income, exclusion of interest on state and local bonds for pollution control and waste disposal facilities, and reimbursed employee parking expenses.⁴² To the extent that the tax system effectively subsidizes activities with negative externalities, the prospects for a double dividend from imposing revenue-neutral taxes on these activities is enhanced.

6. Conclusions

This paper uses a simple numerical model to demonstrate the potential importance of tax-favored consumption for the general equilibrium welfare effects of environmental policies. When part of consumer spending is deductible from labor taxes, the tax system distorts the allocation of consumption in addition to the labor market. In this setting the welfare gain from using environmental tax revenues to reduce labor taxes can be significantly higher than implied by earlier models that do not allow for tax-favored consumption. As a result, the cost savings from using revenue-neutral environmental taxes or auctioned pollution permits over non-auctioned pollution permits can be dramatically higher than suggested by previous studies. In fact, under certain conditions, the overall costs of an environmental tax

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⁴² For more detail on these types of tax expenditures see Office of Management and Budget (1999).

swap can be negative. These conditions include that at least some of the polluting input is used in the production of tax-favored goods and that the level of pollution taxes is not too high. Our results suggest that taxes on carbon, for example, might be worthwhile to implement—if set at modest levels—even in the absence of clear evidence about the benefits from limiting atmospheric accumulations of carbon dioxide.⁴³

In some sense our results are paradoxical. The presence of tax-favored consumption raises the costs of the tax system and normally one would expect this to imply a smaller optimal size of government (Feldstein (1997)). In contrast we find that the welfare gains from environmental protection through revenue-neutral taxes (or auctioned pollution permits) can be significantly *greater* in the presence of tax-favored consumption. However it is important to emphasize that this result depends entirely on pre-existing inefficiencies within the tax system. A first-best response to these inefficiencies would be to implement direct tax reforms, such as cutting back the deductions for employer-provided health insurance and mortgage interest. Yet, probably because of opposition from adversely affected interest groups, these types of direct reforms have proved difficult to implement, at least in the United States.

We emphasize again the preliminary nature of our findings. There is uncertainty about key parameters underlying the market for tax-favored consumption including the demand elasticity, the relative pollution intensity, and the influence of non-tax factors on the overall level of distortion in the market. In addition our analysis is simplified in a number of respects. For example, we ignore the possibility of feedback effects on labor supply from environmental improvement, and we do not model the impact of the tax system on distorting the consumption/investment margin and the choice among alternative investment assets. Nonetheless our analysis clearly illustrates that the presence of tax deductions can substantially affect the overall welfare impacts of environmental policies, under a wide range of assumptions about parameter values. In short, tax deductions are important to incorporate in any comprehensive efficiency analysis of environmental policies.

Finally, we note that the results may have less relevance for countries other than the United States. For example, in Britain mortgage interest tax relief has now been phased out, and most people rely on the National Health Service rather than (subsidized) private health insurance.

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⁴³ Of course, this crucially assumes that all new sources of revenues will be used to cut distortionary taxes. Some recent public choice analyses suggest that at least part of new revenues sources are likely to be used for public spending (Becker and Mulligan (1997), Brett and Keen (1998)). In this case the prospects for a double dividend are likely to be smaller, unless the additional spending generates social benefits well in excess of dollar outlays. On the other hand, a number of environmental taxes in Holland have been implemented in a revenue-neutral fashion. In Germany the new Social Democratic/Green Party Coalition government is proposing similar environmental tax swaps.

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Appendix A. Formal Derivation of Welfare Effects

Here we provide a formal derivation of the welfare effects discussed in Section 2 for the pollution tax with lump-sum replacement and with the strong revenue-recycling effect. For simplicity we focus on incremental policy changes (rather than the non-marginal changes shown in Figure 1). All variables are as defined in the text.

Suppose household utility is:

$$(A1) \quad U(X, Y, \bar{L} - L) - \phi(Z)$$

and the household faces the budget constraint:

$$(A2) \quad (1 - t_N)p_X(\tau)X + p_Y(\tau)Y = (1 - t_N - t_C)L + G$$

where the prices of goods depend on the pollution tax τ .⁴⁴ Households choose X , Y and L to maximize (A1) subject to (A2), taking Z as given. The solution to this problem is the (uncompensated) demand and labor supply functions. These functions can be expressed as follows:

$$(A3) \quad X(\tau, t_N, t_C, G), \quad Y(\tau, t_N, t_C, G), \quad L(\tau, t_N, t_C, G)$$

The derived demand for the polluting good can also be expressed as a function of the exogenous variables:

$$(A4) \quad Z(\tau, t_N, t_C, G)$$

Substituting (A3) and (A4) into (A1) gives:

$$(A5) \quad V(\tau, t_N, t_C, G) - \phi(Z(\tau, t_N, t_C, G))$$

where V is indirect utility from non-environmental goods. From Roy's identity

$$(A6) \quad \frac{\partial V}{\partial \tau} = -\lambda Z \quad \frac{\partial V}{\partial t_N} = -\lambda(L - X) \quad \frac{\partial V}{\partial t_C} = -\lambda L \quad \frac{\partial V}{\partial G} = \lambda$$

⁴⁴ Since firms are competitive and supply curves are perfectly elastic we do not need to explicitly model firm behavior. The tax on the polluting input is fully passed on to consumers in the form of higher product prices.

where λ is the marginal utility of income and we have normalized p_X to unity.

(i) *Pollution tax with lump-sum replacement*

Differentiating (A5) with respect to τ and holding t_N and t_C constant, and using (A6), gives:

$$(A7) \quad \frac{1}{\lambda} \frac{dV}{d\tau} = -Z + \frac{dG}{d\tau} - \frac{\phi'}{\lambda} \frac{dZ}{d\tau}$$

where

$$(A8) \quad \frac{dZ}{d\tau} = \frac{\partial Z}{\partial \tau} + \frac{\partial Z}{\partial G} \frac{dG}{d\tau}$$

The government budget constraint is:

$$(A9) \quad G = (t_N + t_C)L - t_N X + \tau Z$$

Totally differentiating (A9) holding t_N and t_C constant, we can obtain:

$$(A10) \quad \frac{dG}{d\tau} = (t_C + t_N) \frac{dL}{d\tau} - t_N \frac{dX}{d\tau} + Z + \tau \frac{dZ}{d\tau}$$

where the first two price coefficients on the right-hand side are analogous to (A8). From (A7) and (A10)

$$(A11) \quad \frac{1}{\lambda} \frac{dV}{d\tau} = \left(\frac{\phi'}{\lambda} - \tau \right) \left(-\frac{dZ}{d\tau} \right) - t_N \frac{dX}{d\tau} + (t_C + t_N) \frac{dL}{d\tau}$$

The left-hand side of this expression is the general equilibrium (marginal) welfare effect (in dollars) and the terms in the right hand-side correspond to the Pivovian welfare gain, the subsidy-interaction effect, and the tax-interaction effect discussed in Section 2.

(ii) *Pollution tax with Strong Revenue-Recycling Effect*

The difference between this policy and the previous one is that the extra revenue, $dG/d\tau$, is used to reduce t_N rather than increase the lump-sum transfer. Thus, the welfare effect is equal to that in (A11) plus:

$$(A12) \quad \frac{1}{\lambda} \left\{ -\frac{\partial V}{\partial G} + \frac{\partial V}{\partial t_N} \left(-\frac{dt_N}{dG} \right) \right\} \frac{dG}{d\tau}$$

that is, we subtract off the gain in utility from increasing G and add on the gain in utility from reducing t_N .

Totally differentiating (A9) with respect to t_N and G we can obtain (setting $\tau=0$)

$$(A13) \quad \frac{dt_N}{dG} = \left\{ L + t \frac{dL}{dt_N} - t_N \frac{dX}{dt_N} - X \right\}^{-1}$$

where $t = t_C + t_N$,

$$(A14) \quad \frac{dL}{dt_N} = \frac{\partial L}{\partial t_N} + \frac{\partial L}{\partial G} \frac{dG}{dt_N}$$

and similarly for dX/dt_N . Substituting (A13) and (A6) in (A12) gives:

$$(A15) \quad MEB^N \frac{dG}{d\tau}$$

where

$$(A16) \quad MEB^N = \frac{-t \frac{dL}{dt_N} + t_N \frac{dX}{dt_N}}{L - X + t \frac{dL}{dt_N} - t_N \frac{dX}{dt_N}}$$

MEB^N is the MEB of the non-comprehensive tax; that is, the welfare loss from raising an extra dollar of revenue from increasing t_N . The numerator in (A16) is the welfare loss in the labor market from an incremental increase in t_N (i.e. the wedge between the gross and net wage multiplied by the reduction in labor supply) plus the welfare loss from the increase in tax-favored consumption (i.e. the subsidy wedge between the supply and demand price for X times the increase in X). The denominator is the additional revenue from an incremental increase in t_N (from differentiating $(t_C + t_N)L - t_N X$).

Differentiating (A9) with respect to τ and G and substituting in (A15) gives:

$$(A17) \quad MEB^N \left\{ Z + t \frac{dL}{d\tau} - t_N \frac{dX}{d\tau} \right\}$$

when $\tau=0$. This is the (marginal) strong revenue-recycling effect. It equals the MEB times the revenue raised by increasing the pollution tax, net of the reduction in labor tax revenue and the implicit change in subsidy payments for X .

Appendix B. Deriving a Formula for the MEB

From the Slutsky equations:

$$(B1) \quad \frac{\partial L}{\partial t_N} = \frac{\partial L^H}{\partial t_N} - \frac{\partial L}{\partial G} (L - X); \quad \frac{\partial X}{\partial t_N} = \frac{\partial X^H}{\partial t_N} - \frac{\partial X}{\partial G} (L - X)$$

where “ H ” denotes a Hicksian (compensated) price effect. From (B1), (A14) and the analogous expression for dX/dt_N , and (A16):⁴⁵

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⁴⁵ Note that $\frac{\partial L}{\partial t_N} = -\frac{\partial L}{\partial(1-t)}$; $\frac{\partial X}{\partial t_N} = -\frac{\partial X}{\partial(1-t_N)}$ and the same applies for the Hicksian price effects.

$$(B2) \quad MEB^N = \frac{\frac{t}{L} \frac{\partial L^H}{\partial(1-t)} - s_X \frac{t_N}{X} \frac{\partial X^H}{\partial(1-t_N)}}{1 - \frac{t}{L} \frac{\partial L}{\partial(1-t)} - s_X \left\{ 1 - \frac{t_N}{X} \frac{\partial X}{\partial(1-t_N)} \right\}}$$

where $s_X = X/L$. Finally, we can obtain equation (2.2) by substituting the following formulas for the Marshallian and Hicksian labor supply elasticities (ε_L^M and ε_L^H), and the Marshallian and Hicksian own price elasticities of demand for X (η_X^M and η_X^H), expressed as positive numbers:

$$(B3) \quad \varepsilon_L^M = \frac{\partial L}{\partial(1-t)} \frac{1-t}{L}; \quad \varepsilon_L^H = \frac{\partial L^H}{\partial(1-t)} \frac{1-t}{L}; \quad \eta_X^M = -\frac{\partial X}{\partial(1-t_N)} \frac{1-t_N}{X};$$

$$\eta_X^H = -\frac{\partial X}{\partial(1-t_N)} \frac{1-t_N}{X}$$

Table 1. Estimated Losses in Personal Income Tax Revenues by Function (1995)

	In \$billion	% of labor income
<i>Included categories</i>		
Health	64.4	5.7
Employer provided medical insurance	60.7	
Medical expenses	3.7	
Housing	57.9	5.1
Mortgage interest on owner-occupied homes	51.3	
Exemption from passive loss rules for \$25,000 of rental loss	4.3	
Credit for low income housing investments	2.3	
Miscellaneous ^a	17.7	1.6
Total	140.0	12.4
<i>Excluded categories (greater than \$10 billion)</i>		
Pension contributions (employer and employee)	55.5	
Set-up basis of capital gains at death	28.3	
Deductions for state and local income tax	27.3	
Accelerated depreciation of machinery and equipment	19.4	
Charitable contributions	18.9	
Deferral of capital gains on home sales	17.1	
OASI benefits for retired workers	16.9	
Property tax on owner occupied homes	14.8	
Interest deduction for state and local debt	12.4	
Interest on life insurance savings	10.4	
Total	221.0	19.6

Source: *Statistical Abstract of the United States*, 1995, Table 523. Gross labor income in 1995 is calculated by adding wages and salaries (\$3442 billion), other labor income (\$402 billion), employer contributions for social insurance (\$365 billion) and sales and excise tax revenues (\$298 billion). This gives \$4507 billion. These figures are from Table B-28 of the *Economic Report of the President* (1999) and Table 478 of the *Statistical Abstract of the United States*. We divide the above revenue losses by 0.25, and express the result relative to gross labor income, to obtain the shares reported on the last column.

^a Includes group life insurance (2.9), child care (2.9), employee parking (1.9), workman's compensation benefits (4.5), disability insurance benefits (1.9), benefits for dependents and survivors (3.6).

Table 2. Alternative Scenarios for Key Parameters

Parameter	Low MEB	Medium MEB	High MEB
s_X	0.11	0.13	0.15
η_X^M	1.00	1.20	1.40
η_X^H	0.89	1.12	1.35
ε_L^M	0.10	0.15	0.20
ε_L^H	0.30	0.40	0.50
MEB^N	0.31	0.46	0.56
MEB^C	0.21	0.30	0.38

Note: See Section 2 for notational definitions.

Figure 1

(a)

(b)

(c)

Figure 2. Marginal Costs

Figure 3. Total Costs

Figure 4. Varying the Pollution Intensity of Tax-Favored Consumption

Figure 5. Welfare under the Pigouvian Rule

Figure 6. Optimal Policies

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