



CAEPR Working Paper  
#2006-017

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November 8, 2006

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# Green taxes and double dividends in a dynamic economy

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November 7, 2006

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<sup>2</sup>We are thankful to Steve Cassou, Joseph Haslag, Thomas Renström, Akihito Asano, Jean Christophe Perea and participants at the MSU macroeconomics study group for their helpful comments. All remaining errors are our responsibility.

## **Abstract**

This paper examines a revenue neutral green tax reform along the lines of the Double Dividend hypothesis. Using a dynamic general equilibrium model calibrated to the US economy, we find that increasing gasoline taxes and using the revenue to reduce capital income taxes does indeed deliver both types of welfare gains: from higher consumption of market goods ( an efficiency dividend), and from a better environmental quality (a green dividend), even though in the new steady state environmental quality may worsen. We also find that, given the available evidence on how much households are willing to pay for improvements in air quality, the size of the green dividend is very small in absolute magnitude, and much smaller than the efficiency dividend.

# 1 Introduction

Green tax reform has become a major policy issue in the OECD countries, no doubt as a response to important environmental issues such as the protection of the ozone layer, local air quality, biodiversity loss, acid rain and global warming. A number of countries such as Sweden, Denmark, the Netherlands, the United Kingdom, Finland, Norway, Germany and Italy all have implemented explicit environmental tax reforms.

The stakes are large. Tax revenues raised from green taxes average about 2% of GDP in OECD countries, but exceed 4% of GDP in some countries. According to Baker and Elkins [2003], the estimates of the impact on U.S. GDP by complying with the Kyoto Protocol vary between a decrease of about 2.5% and an increase of 3% of GDP. This range of 5.5% of the GDP is due, at least in part, to differing policy instruments considered and different modeling assumptions used. The Intergovernmental Panel on Climate Change (in IPCC [2001]) asserts that, in order to comply with the prescribed limits of the Kyoto Protocol, the carbon tax required in the U.S. would be associated with a 0.45% to 1.96% decrease in GDP by the year 2010. This result is obtained under the assumption that the new green tax revenues would be distributed in a lump-sum fashion.

Most of the studies discussed above focus on the effects of introducing new environmental taxes. We believe that this raises important public choice concerns: it is hard to see that substantial new environmental taxes would be

acceptable politically, if they bring about sizeable losses in terms of average income. It is interesting to note that in a poll conducted in the U.S. in 1998, 70% of respondents were in favor of an increase in energy taxes if the extra tax revenue were to be used to decrease pre-existing income or payroll taxes (see International Communications Research [1998]). These results indicate that revenue recycling, that is, using new revenues from green taxes to decrease pre-existing distortionary taxes, may make green taxes politically feasible.

Revenue recycling raises the possibility that green tax reform may yield a double dividend. The Double Dividend Hypothesis is nicely expounded in Goulder [1995a] and Bovenberg [1999]. Apart from increasing welfare due to lower pollution externalities, a 'green' dividend, environmental taxes raise revenue that can be used to lower other pre-existing tax distortions, resulting in welfare gains from a smaller deadweight loss of the tax system, or 'efficiency' dividend. Because of its appealing nature, environmental tax reform has been labeled a 'no regret option.' This paper examines the effects of a particular environmental tax reform in the U.S. along the lines of the Double Dividend Hypothesis.

For policy purposes there are two strands of literature that are of direct relevance to this paper, one is normative, the other is positive. The first strand is concerned with what is the optimal tax structure. In particular, it examines whether in the presence of preexisting distortions, the optimal environmental tax lies above its Pigovian level. Here, the distortionary effect of increasing green taxes above the level at which the marginal pollution dam-

age is internalized should be compared to the efficiency gains from reducing other taxes. In an influential paper, Bovenberg and de Mooij [1994] examine whether increasing the tax rate on a polluting good from its Pigovian level, and reducing pre-existing labor taxes in a revenue neutral fashion, will deliver a welfare gain. Their main finding shows that, although environmental quality improves, the efficiency dividend does not materialize. In that model, green taxes turn out to be more distortionary at the margin than the labor tax, by virtue of their effect on the composition of the production bundle. This important result has become a stepping stone, and has proved robust to a number of extensions, including capital accumulation dynamics (e.g. Bovenberg and Goulder [1996] and Bovenberg and Smulders [1996]). A second strand of this literature is positive in nature. It asks what are the specific economic effects of a particular, perhaps hypothetical, policy reform. In a very influential paper in macroeconomics, Lucas [1990] finds that shifting capital income taxation completely to labor income taxation has negligible effects on long-run economic growth in a model of endogenous growth which is calibrated to the U.S. economy.

In environmental economics, the papers that falls in this category are Jorgenson and Wilcoxon [1993a] and Jorgenson and Wilcoxon [1993b]. Jorgenson and Wilcoxon [1993a] estimate a model for the US using post war data. Simulations from this model suggest that a carbon tax would have qualitatively different impacts on long-run GDP depending on the preexisting taxes that are reduced. The authors also note that the costs of keeping

CO2 emissions below predetermined standards would increase with higher levels of GDP growth. We believe that this is an interesting insight. A similar theoretical possibility was already mentioned by Koskela and Schob [1999], and considered in more detail by Bayindir-Upmann and Raith [2003], who showed that, in a distorted labor market, substituting green taxes for labor taxes would increase employment and output and have eventually produce a detrimental effect on the environment. After Jorgenson and Wilcoxon [1993a], Goulder [1995b] used a calibrated model to consider different tax recycling policies after a carbon tax was imposed, and found that green tax reform will invariably reduce the efficiency of the tax system. Finally, Zhang [1998] uses a dynamic general equilibrium model to assess the macroeconomic effects of reducing carbon dioxide emissions in China.

The current consensus of the effects of green tax reform is summarized by Lans Bovenberg in his preface to de Mooij [2000], "Whereas the second dividend may be in doubt, the first dividend (i.e. a cleaner environment) remains a powerful reason for the introduction of pollution taxes." This claim is strengthened by a report by the OECD [2001] which summarizes the result of the literature on revenue recycling as follows: In 65% of all simulations where additional green tax revenues were used to cut social security contributions, GDP rose as a consequence of green tax reform. When extra tax revenue was used to cut personal income taxes, only 23% of all simulations resulted in a higher GDP.

For any policy discussion it is absolutely critical to know how the green

tax revenue is recycled. Much of the literature on the Double Dividend Hypothesis assumes that green tax revenues are recycled through a decrease in labor taxes. In the models used, labor is often the only primary factor of production (see Parry [1998], for example for a review). While this assumption may be very sensible in the European context where labor markets are distorted by a variety of factors, in the U.S. context, where labor markets are relatively unfettered, it is worthwhile to consider the effects of recycling the green tax revenue through lower capital income tax rates.

We know from the literature on optimal taxation (see Chamley [1986], Judd [1987], Jones et al. [1993] and Atkeson and Kehoe [1999]) that under certain robust conditions the optimal capital tax rate in the long-run is zero. Since many estimates of the marginal capital income tax rates are positive, it is extremely compelling for Policy Purposes to consider a green tax reform that lowers the pre-existing capital income tax distortion and involves revenue recycling through lower capital taxation. For purposes of welfare economics, we know from Lucas [1990] and others that changes in capital incomes taxation have strong welfare effects.

In this paper, we study the effects on national income, investment, consumption and welfare of a green tax reform that raises a tax on a polluting good. This tax reform is revenue-neutral; we lower a sizeable pre-existing distortion by decreasing the capital income tax in order to keep government's share of the GDP constant. We consider both the long-run (steady state) implications and the effects along the transitions. We use a version of the



Cass-Koopmans economy where output is produced with capital and fuel and where fuel is produced with capital. In addition to the standard consumption good, fuel is also a consumption good. Individual utility also depends upon the stock of health which is inversely related to the stock pollutants, which is augmented by fuel.

The main results of our paper are based on the response of investment to changes in the capital tax rate. Empirically, there is now clear evidence that corporate taxes have strong effects on capital accumulation. Using a panel of US firms spanning thirty-six years, Cummins et al. [1994] estimate the responses of investment to changes in corporate taxes, using major tax reforms as natural experiments. Their results point to large responses of firm level investment to changes in tax rates. In Cummins et al. [1996], the authors use the same identifying technique to show that these results are robust across OECD countries.

This paper contributes to the literature on the Double Dividend Hypothesis in several ways. First, we focus on a very particular tax, namely a gasoline tax, rather than a general carbon or green tax. In the U.S., gasoline taxes already exist at the federal and state levels. It is noteworthy that according to the Green Tax German Memorandum (see FOSEV [2004]) ecotaxes in Germany entail the least amount of red tape and have the lowest administrative costs of all German taxes. Policy changes such as increasing the gasoline or fuel tax as considered here are thus very easy to implement.

Second, our results are based on a model calibrated to the U.S. economy.

Our calibration includes two novel features. Most of the literature that uses calibrated models to study the effects of particular policy reforms uses CES utility functions (see, for example, Lucas [1990]). Such utility functions do not match observed price and income elasticities for the demand for gasoline. We, thus, consider a wider class of utility functions which are consistent with these observations. Moreover, we bring into our calibration the large literature on the valuation of environmental amenities (see, for instance, Freeman III [1993]). This literature allows for the calibration of preferences for a cleaner environment and, therefore, for evaluating the environmental and market effects of green tax policy reform in a unified framework.

Third, our analysis shows the importance of the transition dynamics in evaluating the welfare effects of tax reform. All along the transition, we examine the effects that higher levels of capital accumulation resulting from a lower tax on capital earnings will have on environmental quality as well as on the other economic variables, a point first raised by Jorgenson and Wilcoxon [1993a].

Our results show that, because a lower tax rate on capital earnings encourages capital accumulation, the new steady state levels of capital and consumption of the clean good are higher than their pre-reform levels and, as a result, the quality of the environment may worsen in the new steady state. However, in all the cases we consider, at the beginning of the transition a cleaner environment is obtained, and consumption has to be sacrificed in order to build up capital, so that accounting for transition dynamics is nec-

essary in order to access the welfare effects of this policy change. Our results show that both dividends are likely to materialize under relatively general conditions. We also find that the green dividend, or higher discounted utility from a cleaner environment, is much smaller - by as much as one order of magnitude - than the efficiency dividend, or higher discounted utility from the consumption of market goods. These results are broadly consistent with those found in the literature. They complement those found in Bovenberg and de Mooij [1994] and most of the Double Dividend literature in showing that, given current levels of taxes, a green tax reform of the type examined here would achieve both dividends. These results also show that once transitional dynamics are accounted for, the negative impact of growth on the environment as suggested in Bayindir-Upmann and Raith [2003] is not sufficient to reverse the welfare gains obtained from a better environment quality at the beginning of the transition, a point on which the policy literature is silent.

This paper has four other sections. In section 2, the model is presented. In section 3, functional forms and parameter values are chosen. Section 4 presents the results and section 5 concludes the paper.

## **2 The model**

The economy is populated by a large number of infinitely lived individuals. We abstract from population growth and normalize population size to unity.

Preferences of the representative individual are given by

$$\sum_{t=0}^{\infty} \beta^t u(c_t, m_{ct}; h_t), \quad (1)$$

where  $c_t$  is consumption of the single perishable consumption good at time  $t$ ,  $m_{ct}$  is the amount of fuel consumed at time  $t$  and  $h_t$  is the state of health at time  $t$ ,  $\beta$  is the discount factor which is a real number between zero and one, and  $u$  is felicity. We find it useful here to disaggregate consumption goods into two types: one good, which is associated with negative pollution externalities, we call fuel,  $m_{ct}$ , and the other good, which is not associated with such externalities we refer to as the consumption good,  $c_t$ . In the utility function specified in equation (1) the state of health,  $h_t$ , enters as a separate variable. Health here is a stock variable, which is taken as given by each individual, and depends on the aggregate amount of pollution in the economy.

The relationship between health and the aggregate amount of pollution,  $z_t$ , is given by

$$h_t = h(z_t), \quad h' < 0 \quad (2)$$

From a historical perspective, changes in life expectancy and morbidity patterns are more closely linked to economic growth than to changes in pollution levels. Our specification is motivated by widespread evidence that pollution levels have a strong impact on morbidity rates, in particular among children and elderly people (e.g. Schwartz et al. [1994]).

Given that our focus is not on examining the sectoral effects of green tax

reform, we adopt a simple structure for the production technology of market goods, and refer the reader to Jorgenson and Wilcoxon [1993a] for a more disaggregated analysis. The consumption good is produced via a constant returns to scale technology using two inputs, capital  $k_{pt}$  and fuel  $m_{pt}$ . The production function is given by

$$y_t = f(k_{pt}, m_{pt}). \quad (3)$$

Fuel is produced using capital  $k_{mt}$  only, with a production function given by

$$m_t = g(k_{mt}). \quad (4)$$

There are two stock variables in this economy, physical capital ( $k_t$ ) that can be used in the production of the consumption good ( $k_{pt}$ ) or fuel ( $k_{mt}$ ) (so  $k_t = k_{pt} + k_{mt}$ ), and the stock of pollution ( $z_t$ ). These two stock variables evolve according to

$$k_{t+1} = (1 - \delta)k_t + i_t, \quad (5)$$

$$z_{t+1} = (1 - \delta_z)z_t + m_t, \quad (6)$$

where  $i_t$  is investment in physical capital at time  $t$ . In this economy, fuel  $m_t$  can be used as an input in the final goods sector,  $m_{pt}$ , or consumed,  $m_{ct}$ , so  $m_t = m_{pt} + m_{ct}$ . The initial endowments are  $k_0$  and  $z_0$ .

The government in this economy collects taxes on capital income at the uniform rate  $\tau_k$ , and taxes on household fuel consumption and fuel use by firms at the rate  $\tau_m$ . All tax revenue is rebated in a lump sum fashion to the households.

The representative household solves the problem

$$\max_{(c_t, k_{t+1}, m_{ct})_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t u(c_t, m_{ct}; h_t), \quad (7)$$

subject to

$$\sum_{t=0}^{\infty} p_t (c_t + i_t + (1 + \tau_m) w_t m_{ct}) = \sum_{t=0}^{\infty} p_t ((1 - \tau_k) q_t k_t + \pi_{mt} + T_t),$$

$$k_{t+1} = (1 - \delta) k_t + i_t,$$

given

$$k_0, \{p_t, q_t, w_t, h_t\}_{t=0}^{\infty},$$

where  $p_t$  is the price of final goods at time  $t$ ,  $w_t$  is relative price of fuel compared with final goods at time  $t$ , and  $q_t$  is the return to capital at time  $t$ . Here  $\pi_{mt}$  are profits from producing fuel and  $T_t$  are the lump sum transfers from the government. The final goods producing firm solves the problem

$$\max_{\{k_{pt}, m_{pt}\}} f(k_{pt}, m_{pt}) - q_t k_{pt} - (1 + \tau_m) w_t m_{pt}. \quad (8)$$

The fuel producing firm solves the problem

$$\max_{\{k_{mt}\}} w_t g(k_{mt}) - q_t k_{mt}. \quad (9)$$

We do not allow the government to run a deficit or surplus, so the government budget constraint each period is

$$\tau_m w_t (m_{ct} + m_{pt}) + \tau_k q_t k_t = T_t. \quad (10)$$

An equilibrium for this economy is an allocation for the representative household  $\{c_t, m_{ct}, k_{pt+1}, k_{mt+1}\}_{t=0}^{\infty}$ , an allocation for the final goods producing firm  $\{k_{pt}, m_{pt}\}_{t=0}^{\infty}$ , an allocation for the fuel-producing firm  $\{k_{mt}\}_{t=0}^{\infty}$  and prices  $\{w_t, q_{pt}, q_{mt}\}_{t=0}^{\infty}$ , which together with a sequence of health states  $\{h_t\}_{t=0}^{\infty}$  satisfy

1. the household's allocation solves the maximization problem in (7),
2. the final goods producing firm solves the maximization in problem (8),
3. the fuel-producing firm solves the problem in (9),
4. the fuel and capital markets clear.
5. the government budget constraint (10) is satisfied, and
6. the state of health satisfies (2).

### 3 Calibration

For policy purposes it is crucial to understand how all relevant economic variables respond to changes in the policy instruments. Without imposing any further structure on the model, we cannot derive any (numerical) results and hence cannot determine the economic effects of policy reform. We therefore choose particular functional forms and parameter values so that the equilibrium in our model matches data for the US economy.

For the utility function, we need to choose a functional form that allows us to match the observed income and price elasticities for household fuel

demand. In most standard utility functions, such as Cobb-Douglas or CES, the implied income elasticity is unity, but typical estimates of this elasticity are much lower. To allow for varying income elasticities we pick the following utility function:

$$u(c_t, m_{ct}; h_t) = \frac{1}{1 - \sigma} (h_t^\eta (\theta c_t^\xi + (1 - \theta) m_{ct}^\rho)^{1 - \eta})^{1 - \sigma},$$

$$\xi > 0, \rho > 0, 0 < \theta < 1, 0 < \eta < 1, \sigma \geq 1. \quad (11)$$

For the production technology we choose a CES production function. This functional form allows for a response of input use to changes in relative prices in accordance with microevidence, as will be discussed below. The production function is given by

$$f(k_{pt}, m_{pt}) = A[\chi k_{pt}^\alpha + (1 - \chi) m_{pt}^\alpha]^{1/\alpha}, \quad A > 0, \alpha < 1, 0 < \chi < 1. \quad (12)$$

The production function for fuel is Cobb-Douglas in one input, capital, so that

$$g(k_{mt}) = E k_{mt}^\psi, \quad 0 < \psi < 1. \quad (13)$$

Finally, the relationship between health and pollution is given by

$$h(z_t) = 1/z_t. \quad (14)$$

Given that in our exercise  $z_t$  will display only small deviations around its steady state, and that preferences for health are calibrated -as will become clear below- so that these deviations have a given welfare cost, equation 14 effectively places no restrictions on the results other than those mentioned in



the previous section, when discussing the general form of the health-pollution relationship.

We calibrate our model to the US economy. The benchmark parameters we use are illustrated in Table 1. Calibrating the utility function to long-run data is a bit tricky since preferences are not homothetic and expenditure shares do depend upon the level of income. We thus pick preference parameters  $\xi$  and  $\rho$  that match observed income and price elasticities for gasoline demand at the steady state. Espey [1996] conducts a meta analysis of elasticity estimates for gasoline demand, and reports that estimates are consistent across estimation methods, with a mean price elasticity of  $-.53$  and a mean income elasticity of  $.64$ .

These preference parameters imply demand behavior that is broadly consistent with other international experience as well. After the introduction of the eco tax in Germany in 1999 to 2003, gasoline and fuel consumption fell for four years in a row for the first time, the use of public transport increased and carbon dioxide emissions were cut by 6 to 7%. According to Hibiki and Arimura [2005], in Japan nitrogen monoxide pollution was reduced by about 75% following an increase in the diesel fuel tax. All of this is evidence that fuel demand is responsive to changes in fuel prices or fuel taxes. It is this responsiveness that we are trying to capture with our specification of preferences.

To choose a value for the parameter  $\eta$  we rely on a large literature on the valuation of environmental quality. The purpose of this literature is to assess

the households' marginal willingness to pay (MWTP) for a decrease in the pollution levels. A first approach, pioneered by Ridker and Henning [1967] is based on the observation that differences in pollution levels across communities can be used to identify -via differences in property values- the value assigned to a better environmental quality. In a recent paper, Smith and Huang [1995] presents results of a number of studies that use this approach, summarized in table 2. The authors report that the distribution of MWTP for a reduction in Total Suspended Particulate (TSP) is highly skewed, with the mean being nearly five times the median (109.90 vs. 22.40 1983 dollars).

A different approach uses contingent valuation methods to assess MWTP for improvements in pollution levels. Brookshire et al. [1982] shows that property value premia should always exceed MWTP measures derived from contingent valuation methods, and finds empirical support for this result. In this paper, we will use the results reported by Smith and Huang [1995]. To be useful for our purposes, these results need to be converted in a format interpretable as a  $x\%$  reduction in consumption being equivalent to a  $y\%$  improvement in air quality. To convert the reported MWTP into a  $\%$  reduction in consumption, we use the model real interest rate of 4.5% to annuitize the MWTP, and express it in percentage of mean US disposable household income for 1983. We then convert 'marginal' reductions in TSP into percentage changes by using mean levels of TSP for a sample of 18 cities <sup>1</sup> (Smith and

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<sup>1</sup>Although the focus in this paper is on pollution by  $CO_2$ , results in Brookshire et al. [1982] provide strong evidence that behavioral responses to TSP and  $CO_2$  are highly correlated

Huang [1995], table 3). We find that households are willing to pay an annuity of .014% of their income in exchange for a .56% permanent improvement in air pollution levels.

Using this information,  $\eta$  is selected such that households are indifferent between a 1% steady state reduction in air quality and a .025% steady state reduction in consumption of market goods. This ratio is consistent with the estimated benefits from air pollution reduction reported in Bender et al. [1980], of 708 to 1,781 US\$ for a 10% reduction (720 US\$ in our model, for a comparable reduction).

For the elasticity of substitution (ES) parameter,  $\alpha$ , we follow the literature on capital-energy substitution. A large body of research has attempted to identify the degree of substitutability between capital and energy after the first oil crisis (see Kemfert and Welsch [2000] for an estimate for Germany in the context of  $CO_2$  reductions and Apostolakis [1990] for a review). When estimating the Hicksian elasticity of substitution, cross section data usually suggests that capital and energy are substitutes, while panel datasets provides evidence of complementarity. Thompson and Taylor [1995] provide a brief survey of the literature, and argue that Hicksian elasticities of substitution are inherently difficult to identify in this problem. They show that the Morishima elasticity of substitution provides consistent estimates across different datasets. These estimates are almost all positive (98%, compared to 70% for Hicksian elasticities), with a mean of .76 and a variance of .25,

making energy and capital Morishima substitutes <sup>2</sup>.

Data on output and consumption show that fuel usage by household out of total usage is 30% <sup>3</sup> fuel share of GNP is 7% <sup>4</sup>, and household's expenditure share for fuel is about 3.5 percent <sup>5</sup>. The preference and technology parameters  $\{E, A, \theta, \chi\}$  are chosen to approximate these shares.

We know very little about the technology parameter  $\psi$ . We execute some sensitivity analysis and find that our qualitative results are robust to changes in  $\psi$ . We assume that the depreciation rate for capital is 4%, and a high rate of depreciation for pollution ( $\delta_z$ ) of .8, consistent with our focus on  $CO_2$  emissions.

The Statistical Abstract of the United States 1999, table 793 shows that state gasoline taxes averaged 19 cents a gallon in 1996. Together with a federal gasoline tax of 18.4 cents, and given that before tax gasoline prices were 74 cents a gallon, the average tax rate for gasoline is around 50%.

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<sup>2</sup>The Morishima elasticity of substitution is  $-\frac{1}{\alpha-1}$ , while the Hicksian measure has a more cumbersome form, but its sign is given by the sign of  $\frac{\alpha}{\alpha-1}$ . If we use a Morishima ES of .76 for the calibration, capital and fuel are then also Hicks substitutes, in accordance with most of the evidence drawn from cross-section data

<sup>3</sup>The Statistical Abstract of the United States 1999, table 955 contains data on fuel use which is broken down into the following categories: residential and commercial, industrial, and transportation. We assign 50 percent of fuel use in the residential and commercial category to fuel use in consumption. Over the period from 1970 - 1997, households used 30.75 percent of all fuel.

<sup>4</sup>According to the Statistical Abstract of the United States table 958 and table 727, expenditure on fuel as a fraction of GDP in the US for 1995 is about 7%.

<sup>5</sup>This is slightly lower than the average share of household income allocated to fuel estimated by Chernick and Reschovsky [1997].

## 4 Results

This section contains the heart of our policy analysis. We study how changes in gasoline taxes influence welfare via changes in all relevant economic variables taking all general equilibrium interactions into consideration.

We begin by reporting the results of our main experiment <sup>6</sup>, a revenue neutral tax change. In this experiment, we raise the fuel tax and adjust the capital tax to keep the government share of GDP constant at 35%. For ease of exposition, we concentrate first on steady-state comparisons, and examine the transition path later.

Figure 1 shows fuel usage in steady state as the tax on fuel increases for the baseline parametrization. Although it is not evident from looking at it, this figure shows a steady state level of aggregate fuel consumption that is not monotonic in the tax rate on fuel. In fact, fuel use by household is monotonically declining in the tax rate, as the substitution effect dominates the income effect because of similar magnitudes of the price and income elasticities, but larger increase in the steady state relative price of fuel (price change) with respect to the increase in the capital stock (income change). Fuel use by firms, however, increases in the green tax rate, since higher tax rates on fuel are accompanied by lower capital tax rates, and therefore higher steady state levels of the capital stock. When the fuel tax rate is low

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<sup>6</sup>To solve this model, we first obtain the steady state using a Newton-Raphson procedure, then we linearize the first-order conditions around the steady state and solve the resulting difference equations. The approximation errors that result are very small, with the euler residuals  $\frac{u_c(t)}{u_c(t+1)\beta(1+r_{t+1}-\delta)} - 1$  being of the order of  $10^{-6}$ .

(high), the former (latter) effect tends to dominate <sup>7</sup>, giving a hump shaped relationship between tax rates and aggregate fuel usage.

The steady state levels of the capital stock as  $\tau_m$  changes are depicted in figure 2. While the amount of capital devoted to fuel production stays roughly constant, as  $\tau_m$  increases and the tax on capital income is reduced, capital in the final goods producing sector increases until the after tax rate of return on capital equals the subjective rate of preference.

We now examine the transition path for all variables after the tax on fuel  $\tau_m$  increases from the baseline level of .5 to .55. Figures 4 to 5 show the transition path from period 11 (time 1), when the policy change occurs. At time 1, the higher tax rate on fuel generates, via a substitution effect, a sharp decrease in fuel consumption (figure 3). The lower tax rate on capital earnings, however, creates incentives to accumulate capital (figure 4). Since fuel is an input in the production of the capital good, fuel consumption by firms increases monotonically from time 1 (period 11). As capital is accumulated however, decreasing returns to capital in the fuel producing sector implies that the relative price of fuel must increase, so household consumption of fuel further decreases from time 1 on.

Figure 5 shows the evolution of GDP and consumption of the final good. At the time the policy change takes place and the rate of return to capital jumps, more capital is devoted to investment, and consumption of the final good must be sacrificed for a period of about 15 years (years 11-35 in figure 5).

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<sup>7</sup>Aggregate fuel consumption peaks at a fuel tax rate of 90%.

We now turn to the welfare effects of this policy experiment. To disentangle welfare changes from different consumption paths and different pollution stock paths, a measure of compensating variation is used. We first compute the level of discounted utility during the transition to the new steady state, assuming that households enjoy the levels of health of the original steady state. We then calculate by what percentage should consumption (of both fuel and the final good) decrease along the transition path for both discounted utilities (original steady state and transition) to be equal, and label this number the efficiency dividend. Next, we do the same exercise but now holding consumption at the level of the original steady state, and comparing discounted utilities where only the stock of health changes. We label this second number the green dividend. Finally, a measure of aggregate welfare change is computed along the same lines.

Table 3 shows these welfare measures for the baseline case, where  $\tau_m$  increases from .5 to .55, as well as for alternative tax changes and different calibrations. Note that both dividends are always obtained under reasonable parameter values. The efficiency dividend decreases monotonically with the tax rate on fuel, and becomes negative at high levels of  $\tau_m$  (above 150% for the baseline calibration). When simulating a similar policy experiment, Goulder [1995a] reports a negative efficiency dividend, but Jorgenson and Wilcoxon [1993a] finds that output actually increases, in line with our results. With respect to the green dividend, we are not aware of previous work that attempts to measure it, and we find that it is always positive for all reasonable

parameter values <sup>8</sup>, even though environmental quality is likely to be lower at the new steady state, and is certainly lower for all policy changes considered in table 3. The reason why we find positive green dividends across the board is of course that the transition dynamics are very slow, with a half life of about 300 years in the baseline model. To make sense of this result, we should keep in mind that in the data this transition occurs around a balanced growth path, so it is not at odds with the observed growth rates of gasoline consumption in the US.

Since we have calibrated preferences for pollution to be consistent with the evidence, the size of green and efficiency dividends can be compared. The striking feature of table 3 is of course that green dividends are always very small, and much smaller (by about 85% in the baseline case), than efficiency dividends, so that aggregate welfare change can always be approximated by welfare changes from the consumption of market goods. We may question whether this result is sensible. After all, environmental concerns seem to be high on the public policy agenda, as well as in people's perceptions of what matters for quality of life. The point is that, while there is consensus that a cleaner environment is a desirable policy goal, there is strong evidence that actual willingness to pay for a better environmental quality is very low, as shown consistently by the literature reviewed in the previous section.

Summarizing, even though in steady state comparisons the efficiency div-

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<sup>8</sup>When the elasticity of substitution becomes close to zero, the Leontief case, we find that the green dividend actually disappears.



idend always holds, and the green dividend is in doubt, both types of welfare gains will be obtained when transition dynamics are accounted for. Moreover, green dividends are always smaller than efficiency dividends, and very small in absolute terms, so that aggregate welfare effects will likely be well approximated by the efficiency dividend.

## 5 Conclusion

In this paper we have studied whether a modest increase in a green tax - the gasoline tax- is desirable. We have done this in the context of a dynamic model that allows to track all general equilibrium effects. We have calibrated the model to the US economy so as to obtain reasonable quantitative effects. Our analysis also delivers an answer to the question of whether a green tax reform can deliver a double dividend. The answer is yes.

In our model, raising a green tax does indeed allow a pre-existing tax to be decreased, here a tax on capital income. Cutting the highly distortionary capital taxes does reduce the deadweight loss from the tax system given current tax levels, so green tax reform does yield one dividend. If fuel is an input in the production of capital, however, increasing the capital stock raises the demand for fuel which may offset any decline in fuel use due to higher fuel taxes. While this offsetting effect is important in steady state comparisons, it is dwarfed by substitution effects that decrease the consumption of fuel and thus deliver a better environmental quality for a very long period along the transition path. This result certainly depends on the elasticity of substitution

in production between capital and energy. If this elasticity of production were to be substantially smaller than the value we use in our model, this result may be overturned. For the estimates available for the US economy, however, the green dividend is indeed achieved.

It is worth noting that given the low value that households show for the quality of the environment, the size of this welfare gain (the green dividend) is very small in absolute terms, and much smaller than the efficiency dividend. Reconsidering Bovenberg's citation in the introduction of this paper, our results suggest that the green dividend may not be after all a strong argument in favor of the implementation of green tax policy reform. Our analysis does suggest however that policymakers who are contemplating a green tax reform should give serious consideration to how the extra revenue should be recycled. In our paper the largest pre existing tax distortion is a tax on capital income. The welfare gains of green tax reform from being able to correct this particular distortion are large.

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Table 1: Benchmark parameters and data

Preference parameters	
$\beta$	0.979
$\sigma$	3
$\theta$	0.925
$\eta$	0.011
$\xi$	0.453
$\rho$	0.145
Technology parameters	
Final good production	
A	.12
$\alpha$	-0.32
$\chi$	0.98
Fuel production	
E	.9
$\psi$	0.3
Depreciation rate	
$\delta$	0.041
$\delta_z$	0.8
Data	
$\frac{m_c}{m_c+m_p}$	0.3
$wm/GNP$	0.07
$\frac{w(1+\tau_m)mc}{c+i+(1+\tau_m)wm_c}$	.035

Table 2: MWTP in selected studies (from Table 1 in Smith and Huang [1995])

Study	Year of data	Location	MWTP Range (1982-1984 US\$)
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Highest 5 MWTP

Ega [1973]	1960	Hartford	1,612 to 1,807.8
Nelson [1978]	1970	Washington	0 to 1,522
Brookshire et al. [1979]	1977	Southern Cal. Air Basin	577.2
Jackson [1979]	1970	Milwaukee	551.4
Brucato et al. [1990]	1978	San Francisco	500.2

Lowest 5 MWTP

Berry [1976]	1968	Chicago	-1.38
Li and Brown [1980]	1971	Chicago	2.7 to 10.8
Krumm [1980]	1971	Chicago	29
Anderson and Crocker [1971]	1960	Kansas City	16.4 to 31.6
Anderson and Crocker [1971]	1960	St. Louis	17 to 32.7

Table 3: Welfare analysis: Compensating variation (% of consumption)

Calibration	Efficiency dividend	Green dividend	Aggregate welfare change
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Baseline

$\tau_m$ from .5 to .55	.15	.02	.17
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Baseline, alternative tax changes

$\tau_m$ from .35 to .4	.22	.02	.24
$\tau_m$ from .4 to .45	.19	.02	.21
$\tau_m$ from .45 to .5	.17	.02	.19
$\tau_m$ from .55 to .6	.13	.02	.15

Sensitivity analysis ( $\tau_m$  from .5 to .55)

$\eta$ : MWTP is 2 times the baseline	.15	.04	.19
$\alpha$ : ES is .65 (.76-2SD)	.23	.02	.25
$\alpha$ : ES is .87 (.76+2SD)	.08	.02	.1
$\psi = .1$	.24	.01	.25
$\psi = .5$	.05	.03	.08
$\delta_z = .1$	.15	.02	.16
$\delta_z = .99$	.15	.02	.17
$\sigma = 1$	.19	.07	.32

Figure 1: Steady state comparisons: fuel

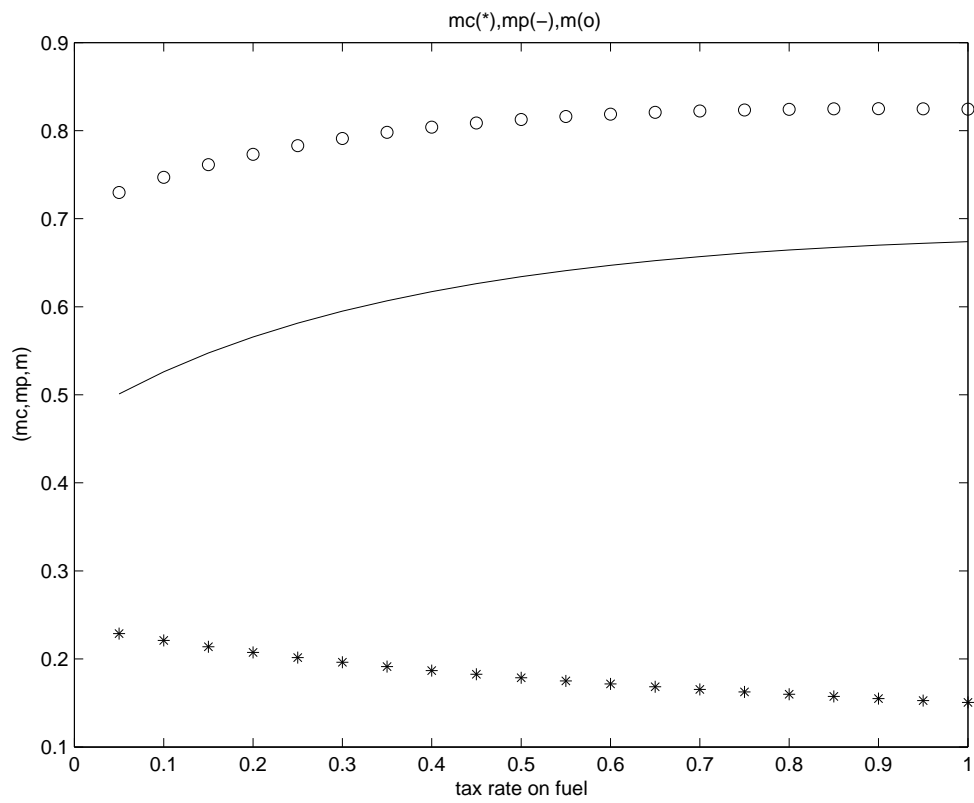


Figure 2: Steady state comparisons: capital

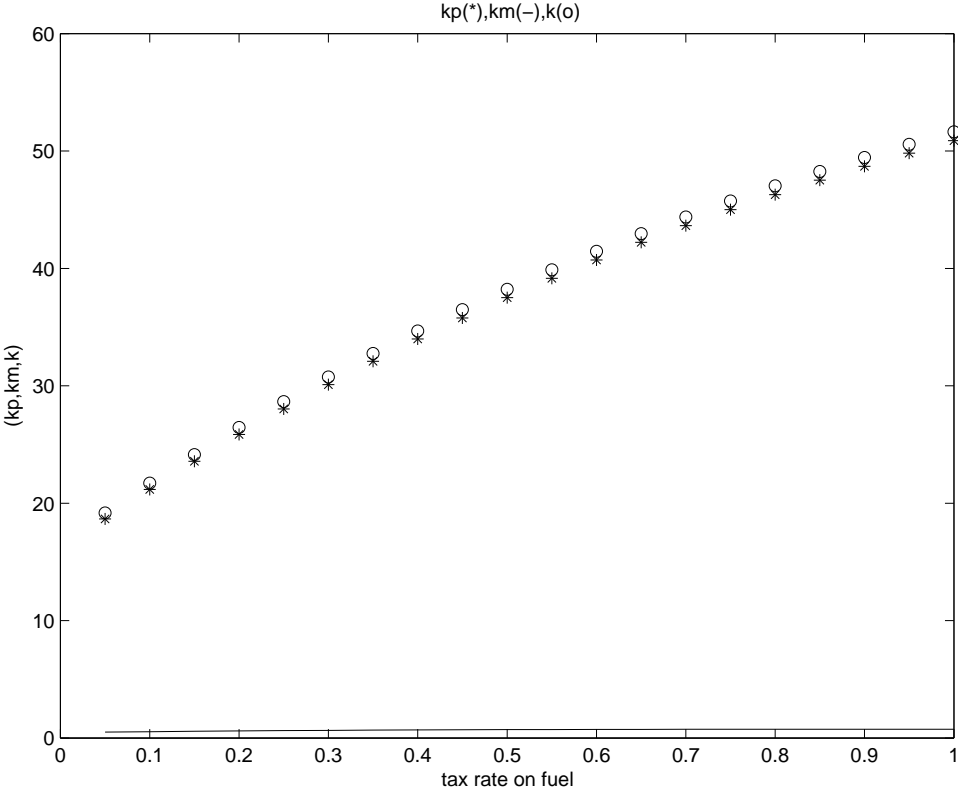


Figure 3: Transition path: fuel

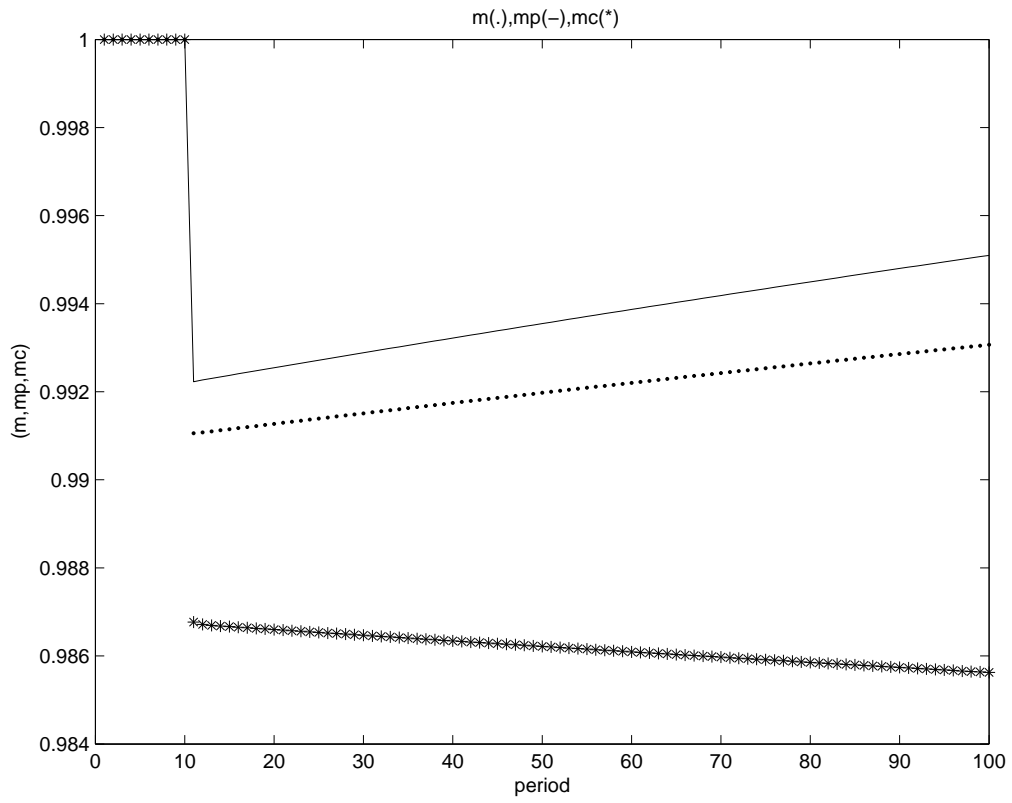


Figure 4: Transition path: capital

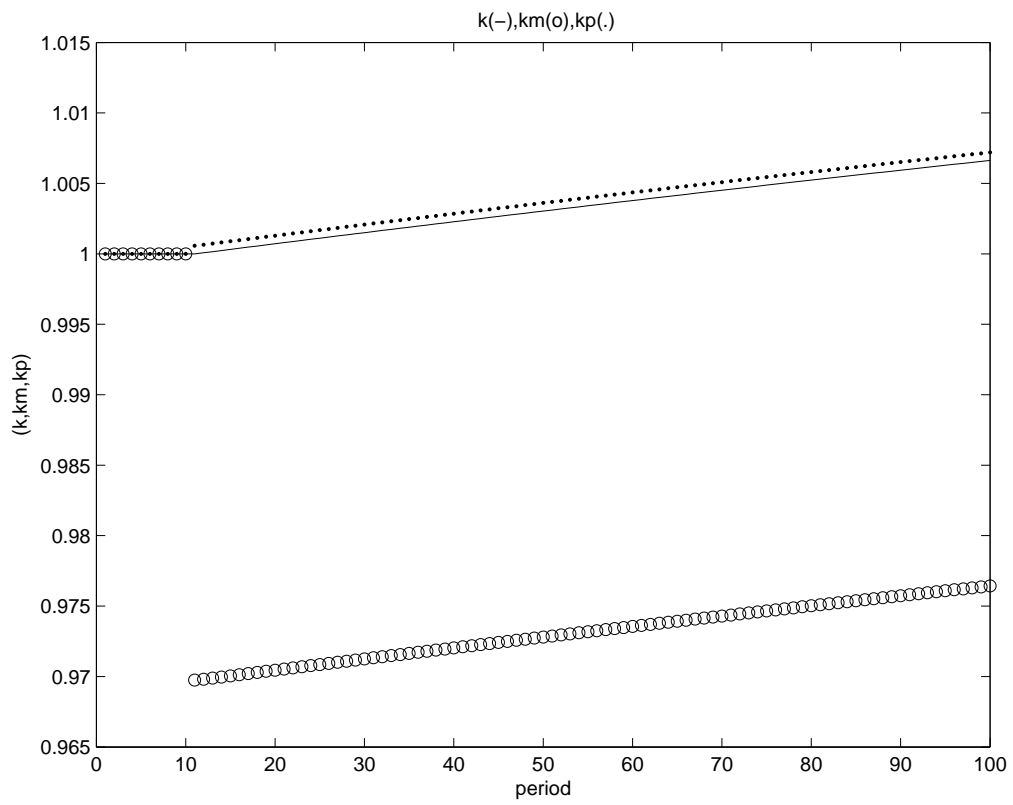




Figure 5: Transition path: GDP and final goods consumption

