Environmental Taxes and Economic Welfare: The Welfare Cost of Gasoline Taxation in the U.S. 1959-99[*]

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Abstract

The purpose of this paper is to provide reasonable estimates for the welfare cost of environmental tax reform in the US economy. Unlike most previous studies that empirically evaluate the deadweight cost of taxation, the model employed here considers explicitly the joint allocation of leisure and commodity demands where the wage rate plays a role both as a form of income and as the price of leisure time. The estimated results of the consumer behavior model indicate that the existing US gasoline tax regime has induced a decrease of gasoline consumption by approximately 4% over the period from 1959 to 1999, while the deadweight cost caused by the tax accounts just for about 0.08% of the consumer full income over the sample period 1959-1999. Moreover, in most years of the sample period, the measures of marginal deadweight cost of gasoline taxation (sample average 0.1882) are relatively small compared to those of labor taxation (sample average 0.2175). This implies a larger efficiency gain in the case of labor taxation in shifting from the existing distortionary taxation to lump sum taxation. These empirical results might suggest the modest possibility of social welfare gains from tax reforms that would shift some of the burden of taxation from labor to energy (e.g., gasoline).

Key words: Environmental taxes, double dividend hypothesis, gasoline taxation, non-separable labor supply effects, AI demand system, marginal deadweight cost

JEL classification: H21; H23; Q28; J22

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I. INTRODUCTION

Economists have greatly increased attention on the question of whether it is possible to use environmental taxes to improve the distorted tax system as well as the environmental quality.[1] Recently this question often arises in the context of measuring the welfare consequences of the revenue-neutral tax swap between corrective commodity taxation and pre-existing distortionary (labor) income taxation. In this case, the welfare effects of cutting one tax at the expense of raising another tax, holding total tax revenues constant, depend critically on the magnitude of marginal deadweight loss of each of these taxes.

As indicated by Pearce (1991), energy-related taxes might offer a so-called "double dividend": these taxes not only might improve the environment, but might also reduce welfare costs of the overall tax system.[2] However, the literature on the double dividend hypothesis was dramatically reframed by Bovenberg and de Mooij (1994), Parry (1995), Oates (1995), Bovenberg and Goulder (1996) and many other authors: in a tax system with a labor income tax, the second-best optimal pollution tax typically lies below the first-best Pigouvian level (or social marginal damages). These recent contributions have claimed that by raising costs and prices, new environmental taxes decrease the real net return to labor and therefore aggravates the distortions of pre-existing taxes. In other words, with other distortionary taxes, environmental regulatory instruments tend to compound those pre-existing distortions, a cost that is recognized as "tax interactions" or "interdependency effects." According to these interpretations, pre-existing distortions significantly raise the costs of all environmental policies relative to their costs in a first-best setting. Thus, the pessimism remains, with a fairly general presumption *against* the possibility of double dividends.

However, we should note that this prior literature is based on a fairly simple model with narrow assumptions and special cases. In particular, these models typically assume weakly separable and homothetic preference structure, which implies that all consumption goods have the same substitutability with leisure and consumer demands for individual types of commodity are required to be proportional to total expenditure.[3] Therefore, if we relax this separability assumption in the utility of the representative

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[1] The problem of whether (and when) a revenue-neutral tax policy can increase welfare might be a leading concern for corrective policy decision-makers.

[2] In general, the environmental benefit is called the first dividend and the non-environmental benefit the second dividend. This "double dividend" issue is reviewed at length in Goulder (1995) and Oates (1995).

[3] Recall that the pioneering findings by Sandmo (1975) demonstrate that the optimal second-best tax on an externality-generating good is a weighted average of a Ramsey component and a Pigouvian component (*i.e.*, marginal environmental damages). So, recent results can be considered a re-interpretation of the well-known Ramsey uniform taxation literature under homothetic separability with a Pigouvian corrective tax. The reason is that any deviation from uniform commodity taxation under this assumption would always increase the efficiency cost of the tax system from a non-environmental point of view.

consumer, the welfare implications of environmental tax reform might not be so skeptical as the literature has argued.[4]

The question of the environmental tax debate above can be addressed only by the empirical welfare measurement of the relevant effective policy effects, taking into account the realistic behavioral responses. One of the common empirical approaches to the evaluation of such a policy is to measure the (aggregate) deadweight loss that results from the introduction of tax distortion into an economic system. The measure of aggregate deadweight loss, as an index of potential welfare change, would be necessary for evaluating the possibilities of social welfare gains from alternative tax policy regimes.

Previous studies have tended to estimate separately the deadweight costs of income taxation and individual commodity taxation. In such cases, they assumed separation of the consumer's labor-leisure decision from the consumption expenditure allocation over individual goods.[5] However, note that the joint modeling of leisure and goods demand would be of critical importance in dealing with transitions between labor income taxes and environmentally-motivated consumption taxes. As long as leisure is not separable from consumption goods, the conventional separation of labor supply modeling from consumer demand modeling could result in misleading conclusions regarding any welfare costs estimates from distiortionary taxation.

In reality, the major source of energy-related or environmental taxes within the household sector in the U.S. is through taxes on consumption of motor fuels such as gasoline. It accounts for about 15 percent of total excise taxes revenue by government. Therefore, to assess the welfare implications of environmentally-motivated taxation, this paper has focused the following questions: how does gasoline tax affect the consumer behavior? what is the corresponding deadweight loss of such a tax? and what is the welfare consequences of gasoline tax compared to ordinary income taxes such as labor tax? [6]

To answer each of these questions, this paper is organized as follows. Using time-series data over the period 1959-1999 in the U.S. economy, first, this paper estimates econometrically a complete demand system of consumer behavior that accounts for the *non-separable* effects of labor supply on individual commodity demands.[7] Then, based on the estimated model of consumer demand responsiveness (*i.e.*, a joint allocation of

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[4] As in much of the recent literature, this paper considers the representative shift from labor income (abstracting capital income part) to environmental taxes or energy-related taxes.

[5] For example, see Stuart (1984), Ballard et al. (1985), Browning (1987, 1994), Feldstein (1999) for income taxation, and Slesnick (1991) for commodity-specific taxation.

[6] For a similar study, see Jorgenson et al. (1992). They examined the efficiency and equity impacts of a carbon tax in the U.S. with an econometric general equilibrium model. However, for this paper, we abstract from the distributional considerations in order to focus on the possibility of double dividend in the context of efficiency aspects with non-separable household labor supply effects by environmental taxation.

[7] In this case, unlike the conventional model with homothetically separable aggregate consumption in the preference structure, we can obtain information on expenditure and price elasticities for goods and the effects of changes in labor supply on individual consumption patterns. However, most papers on empirical welfare measurement of taxation lack this information, thereby providing misleading conclusions on the optimal tax structure.

individual demands and labor supply equations with flexible functional forms), this paper evaluates the commodity-specific deadweight loss of taxation on gasoline and labor. Finally, this paper discusses the welfare implications of the environmentally-motivated taxes.[8]

II. THE CRITICAL IMPORTANCE OF NON-SEPARABLE UTILITY

Since the responsiveness of consumer behavior to changes in after-tax prices is the main determinant of the size of welfare costs, it is important in evaluating environmental tax reforms how we *set out* the assumptions on preference structure and how we obtain the unbiased estimates of the key preference parameters.[9] In fact, the magnitude of the deadweight cost of distortionary taxes critically depends on the estimated parameter values for the structure of consumer preferences. Only unbiased estimates can correctly address the welfare effect of tax-reform induced changes. Yet, most empirical studies using a system of consumer demands are still based on (weakly) separable preferences between commodity demands and labor supply, and even linear Engel curves together. Without clear evidence that labor supply and commodity demands are separable, any welfare cost estimates from demand systems that ignore the interaction between household labor supply and commodity demands are likely to be seriously biased. As implied in Corlett and Hague (1953), Sandmo (1976), and Hanemann and Morey (1992), the separability restriction can result in misleading conclusions concerning the impact of price changes on welfare, because changes in the prices and expenditure bring about overall reallocations between labor supply and individual consumption patterns.

The null hypothesis of separability of leisure from consumption is usually rejected in the econometric literature (for a recent survey on the non-separability issue in empirical welfare measurement, see Slesnick (1998)).[10] Evidence presented by Abbot and Ashenfelter (1976), Barnett (1979), Blundell and Walker (1982), and Browning and Meghir (1991) does not support the separable labor supply effects from commodity demand patterns. In this case, labor-leisure choice affects the demand patterns for individual consumption goods, and, at the same time, changes in the reallocation of consumption goods expenditure give feedback effects on leisure demand.

However, as pointed out in Fullerton and Gravelle (1998) and Parry (1998), most previous analyses on the environmental tax reform have neglected the non-separable labor supply effects on household demand patterns. Examples that assume the separable labor supply include Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996,

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[8] However, the truth regarding the welfare implications of environmental tax reforms could come to us more closely, if we incorporate the distributional concerns with a heterogeneous household framework, as in Slesnick (1991). Considering that distortionary income taxes are used because of individual diversity, the next step of this study would be clear.

[9] According to Stuart (1984), Ballard (1990), and Fullerton (1991), major sources of differences in estimates of marginal excess burden may stem from differences in underlying model structure assumptions rather than uncertainty about the magnitude of various elasticities.

[10] Normatively, the non-separable structure of consumer preferences might shed some light on the desirability of differential as opposed to uniform commodity taxation.

1997), Goulder et al (1997), and Parry et al (1999).[11] So, these models are subject to some severe limitations: private consumption commodities are weakly separable from leisure so that changes in labor supply do not affect the allocation of consumption over different commodities, and, more critically, the sub-utility function for aggregate consumption is homothetic in its arguments, which implies the linear Engel curves and also all the unitary expenditure elasticities for private consumption commodities. In addition, the elasticity estimates employed in these models are often from separate empirical studies that are undertaken for different purposes.[12]

Nonetheless, the previous literature on empirical public finance pays little attention to how the non-separable labor supply affects the welfare cost measurement of the corrective policy instruments. Especially, this consideration is of great significance for the empirical explorations of the 'double dividend' issue in the context of measuring the welfare consequences of taxes on interaction between corrective commodity market and tax-distorted labor market. The reason is that the marginal deadweight loss of energy-related taxes could also depend on how these taxes interacts with pre-existing tax distortions in labor market in the economy with non-separable structure of consumer preferences.

As indicted in Diewert et al (1998), in general, economists have presumed that the deadweight costs of taxation might be minimized by lower marginal tax rates on good things (*e.g.*, working, saving, or investing), by broadening tax bases, by taxing bad things (*e.g.*, pollution, tobacco, or alcohol). In a recent study by Ballard et al. (2000), using a simple CGE model with two final goods (clean and dirty) and the only input labor as corresponded in the analytical model of Bovenberg and de Mooij (1994), they report the strong and wide possibility of double dividends when utility function is separable between goods and leisure but the inner nest of the utility function is assumed not to be homothetic. Their study indicates that for even a modest amount of non-homotheticity component, Bovenberg and de Mooij's result can be reversed dramatically. As another example, an econometric CGE model for New Zealand by Diewert and Lawrence (1996) also indicates the marginal excess benefit (or negative deadweight loss) of tax on motor vehicles (which is pollution-intensive and leisure-intensive good) in the presence of other taxes.

III. DATA

The data set employed in the empirical work consist of annual aggregate time series for the United States on personal consumption expenditures, hours of work, money wage

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[11] In contrast, some few exceptions are made recently in Kim (2002) who generalizes theoretically founded and operational environmental taxation formulas in a second-best world of other existing policy distortions, and shows that, sharply contrary to the impression given by the prior literature, the degree of pre-existing tax distortions does *not* affect the possibility of whether second-best pollution tax is below or above the first-best Pigouvian level.

[12] The results of unwarranted parameter uses would be even more severe, if the parameter estimates are incompatibly mixed from heterogeneous studies for different time periods and different countries.

rates, and nonlabor income covering the years 1959-1999. Since the purpose of this study centers on the interaction of commodity prices and wage rates in the joint determination of both commodity demand and labor supply, we are precluded from the use of purely cross-sectional data sets where price variation is typically ignored. Further, this study, encompassing labor-leisure choice as well as choice among commodities, abstracts from demographic characteristics among consumer units and any distributional consequences from environmental taxes.[13]

The personal consumption expenditure data are compiled from Table 2.6U, 2.7U and 7.5U of the NIPA and combined into the following four mutually exclusive composite commodities:

1. Gasoline and other fuels (O) – expenditures on gasoline, fuel oil, and other fuels including coals, and so on, for transportation, heating, and operation of tools such as power motors.
2. Natural gas (G) – expenditures on natural gas for heating and use of appliances
3. Electricity (EL) – expenditures on electricity for lighting, heating, and use of appliances.
4. Non-energy products (N) – expenditures on non-energy aggregates such as food, clothing, other consumer goods and services, and non-durables.[14]

The price series of commodities are formed by division of the current-dollar composite by the Divisia index for the corresponding constant-dollar composite. As a matter of style, the term ‘full income’ as our income variable is used to designate aggregate consumption expenditure on commodities and leisure. Its use is dictated by the intertemporal separability assumption required to acquire a single period decision in a multiperiod world. The average hourly pre-tax wage rate (w) is estimated by dividing total wages and salaries in the private sector from Table 2.8M and 2.9M of the NIPA by an estimate of total private hours worked from the BLS. The value of leisure is defined as average hourly after-tax wage rate multiplied by the nonwork (or nonmarket) hours of all working age groups.[15] The time endowment (T) of 2400 hours per year is assumed and hence per capita leisure is calculated as 2400−L where L is per capita hours of work supplied by the representative consumer unit during the year under consideration.

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[13] This will require the recognition of heterogeneity of abilities of different consumers (or earning persons) and their differential wage rates, which is one promising opportunity for extending the econometric model in this paper as well as for incorporating inter-temporal choice of endogenous saving.

[14] Note that the data on consumer durables (included in the non-energy products) – treated as investment altering the stock of household capital as well as replacement – is taken directly from the NIPA personal consumption expenditure. However, on theoretical grounds, it would be more valid to use the *service flow* from consumer durables such as the data via the ‘perpetual inventory method’ described in Christensen and Jorgenson (1970).

[15] Due to the deficiency of some data on the hours of government employees and exact labor taxes on personal income, this study assumed that i) hours of work per employee are similar in the government and private sectors, ii) marginal and average tax rates are equal, and iii) both earned and unearned income is taxed at similar rates.

Table-1 contains summary statistics on the series for the consumption data for the three main composite commodity groups and for the three individual types of energy products. Due to the reduction in work hours within the period, the relative share of leisure in full income has been slightly increased. This trend may partly accounts for the increased personal income effects. There is also a relatively large increase in nominal wage rate compared to in other commodity groups, even though the U.S economy experienced a rapid participation of female workers after 1971. The average growth rate in the price of energy products is slightly higher than that of non-energy products. About 60 percent of total household expenditure on energy products is allocated to the expenditure on gasoline and other fuel oils. The dominant tend in individual types of energy is the continued increase in electricity consumption.

Table-1. Sample Statistics for Consumption and Leisure Data in the U.S.

Commodity categories	Shares in full expenditure			Sample means of (natural) log changes
	1959	1999	Sample mean	∆Log Pi
Non-energy (N)	0.8250	0.8129	0.7988	0.0393
Energy (E)	0.0642	0.0368	0.0566	0.0396
Leisure (R)	0.1108	0.1503	0.1446	0.0572
Energy categories	Shares in Total energy expenditure			Sample means of (natural) log changes
	1959	1999	Sample mean	∆log Pi
Gasoline/fuel oils (O)	0.6673	0.5256	0.5836	0.0382
Natural gas (G)	0.1275	0.1204	0.1336	0.0479
Electricitity (EL)	0.2052	0.3541	0.2828	0.0363

Sources: Tables 2.6U, 2.7U, and 7.5U of NIPA, and the data on labor hours estimates of BLS

IV. ESTIMATION OF RELATIVE PRICE AND INCOME EFFECTS

4-1. AIDS Model of Consumer behavior

The household sector in the U.S. consumes energy as a final good for transport, lighting, heating, and use of appliances, and so on. Household behavior in this study is analyzed a complete system of demand functions, describing how the demand for a specific good changes when the price of some good, or the income, changes. The system of demand functions is derived by assuming utility-maximization over full household consumption that includes leisure, energy and all non-energy commodities.

The model used here is a ‘two-stage budgeting’ model which use aggregate data from the national income and product accounts. The advantage of this approach is that at each stage, the number of commodity groups can be kept relatively small. The observations on aggregate consumer behavior in the model include the US time-series data 1959-1999 on expenditure shares and prices for leisure, individual types of energy, and all other non-energy commodities. The first stage concerns the allocation of full expenditure among the three broad categories: leisure (R), energy (E) and non-energy aggregates (N). The second stage incorporates the allocation of total energy expenditure among the three individual types of energy: gasoline and other fuels (O), natural gas (G), and electricity (EL).

The model in this study, however, is distinct from the majority of the U.S. empirical two-stage budgeting studies. Most previous studies in this area have been abstract from (or treating separately) leisure demand, without taking into account the non-separable labor supply effects from consumption patterns. An important feature of the consumer behavior model in this study is that commodity demands need *not* be separable from leisure and also *not* be homothetic. At levels of full expenditure and total energy expenditure increase, individual consumption patterns and labor supply incentive would change, even in the absence of relative price changes.[16] The modeling feature of non-separable structure of consumer preferences enables us to capture critical channels for interactions between energy taxation and labor income taxation, which is typically ignored in most empirical tax incidence analyses.

Formally, it is assumed that the representative consumer expenditures on leisure and commodities are distributed according to an AIDS (See Deaton and Muellbauer, 1980, p.313). The Almost Ideal Demand System (AIDS) assumes that consumer preferences fall within the PIGLOG (price-independent generalized logarithmic) class so that exact aggregation over consumers is possible. This means that the expenditures on a specific commodity, or group of commodities, in relation to full expenditures, can be written as:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln(y/P) + \eta_i T + \varepsilon_i \,, \tag{1}$$

where w_i is commodity i's share of full expenditure, p_j is a price for commodity j, y is income which in this case equals full expenditure, P is the 'consumer price index', T is time index of taste change, and ε_i is the random element. The parameters to be estimated are then α, β and γ.

The consumer price index, P, is determined simultaneously with the expenditure shares, but here used as an approximation, the well-known Stone (1953)'s index which is expressed

$$\ln P = \sum_j w_j \ln p_j \,, \tag{2}$$

which simply implies that the price level on full consumption equals a weighted average of leisure and all commodities prices where the weight equals the expenditure share of each commodity.

In the AIDS model with two-stage budgeting process, we have six different equations in (1) for R, E, and N within the first stage and for O, G, and EL within the second stage. To satisfy the regular requirements by consumer theory, the complete demand system need to hold the following conditions (3), (4), and (5). These conditions are (i) adding-up condition (*i.e*, sum of the expenditure shares equals one), (ii) no money illusion or homogeneity condition (*i.e.*, demands are homogenous of degree zero in all prices and income, and all prices are expressed relative to the price of "other" goods), and (iii) symmetry condition in the usual way:

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[16] If individual types of energy are *homothetcally* separable from non-energy commodities, then consumer demands for individual types of energy at the second-stage are required to be proportional to total energy expenditure (*e.g.*, Jorgenson, Slesnick, and Stoker, 1988).

$$\sum_i \alpha_i = 1,\ \sum_i \beta_i = 0,\ \sum_i \gamma_{ij} = 0,\ \sum_i \eta_i = 0, \tag{3}$$

$$\sum_j \gamma_{ij} = 0, \text{ and} \tag{4}$$

$$\gamma_{ij} = \gamma_{ji}. \tag{5}$$

To calculate AIDS model elasticities, differentiate (1) with respect to prices and income. Then, under regular restrictions, the income (budget) elasticities are given by

$$e_i = \beta_i / w_i + 1. \tag{6}$$

The uncompensated price elasticities are given by

$$e_{ij}{}^u = (\gamma_{ij} - \beta_i w_j) / w_i - \delta_{ij}, \tag{7}$$

where δ_{ij} is the Kronecker delta. Using the Slutsky equation, $e_{ij}{}^c = e_{ij}{}^u + e_i w_j$, we further get the compensated price elastictities.

Since all six equations in the first and second stage model are derived from the same utility function, the whole system can be estimated simultaneously in the efficient manner, with all the restrictions implied by (3), (4), and (5).

4-2. Empirical Results

The estimation results from the U.S. data for the period 1959-1999 are shown in Table-2. The results indicate that most of the estimated parameters in the first and second stage in the model are significantly different from zero and that the degree of explanation is good. These results are used to estimate income (or expenditure) and price elasticities for the demand of the various goods according to (6) and (7), which are presented in Table-3 through Table-5.

Table-3 and Table-4 show that all own-price elasticities have a negative sign, which indicates that a price increase of one specific good has a negative effect on the same good. In this case, own-price elasticities between 0 and -1 implies that a higher price of one good increases its budget share in spite of lower consumption of that good.

According to Table-3, if the price of energy consumption goods increases by 10 percent, everything remaining constant, then energy consumption decreases with approximately 1.16 percent. With considerable precision, all goods have positive aggregate (full) income elasticities, so that all goods are normal goods including leisure. Especially, aggregate energy has the smallest income elasticity, 0.62, of three broad commodity groups. That is, if income, more precisely full expenditure, increases by 1 percent, then demand for aggregate energy increases by 0.62 percent. One interpretation is that energy seems to be a necessary good for the U.S. consumers.

The own-price elasticities of demand for all three types of energy calculated from second-stage model are presented in Table-4. All own-price elasticities within the energy nest have a negative sign, where gasoline and fuel oil is the greatest in absolute value. Natural gas is least elastic among three types of energy, to account for its major use for residential heating and cooking. This result also shows that for the U.S. consumers, energy use for transportation is more price-responsive than that for heating and other appliances. The price effects for aggregate energy and for individual types of energy presented in Table-4 implies that energy-related or environmentally-targeted taxes can have the intended effect in the sense that a higher tax reduces energy consumption in the U.S. economy.

Table-2. Demand System Parameter Estimates for the Period 1959-1999

	Full consumption					
	Constant	*ln* P_N	*ln* P_E	*ln* P_R	*ln* (y/ P)	T
Non-energy products (N)	0.7337	0.2353	-0.0863	-0.1490	0.0101	0.0018
	(0.0186)	(0.0537)	(0.0056)	(0.0317)	(0.0508)	(0.0007)
Energy products (E)	0.0819	-0.0863	0.0454	0.0409	-0.0208	-0.0011
	(0.0064)	(0.0056)	(0.0029)	(0.0071)	(0.0128)	(0.0002)
Leisure (R)	0.1844	-0.1490	0.0409	0.1081	0.0107	-0.0007
	(0.0171)	(0.0317)	(0.0071)	(0.0352)	(0.0491)	(0.0001)

	Energy consumption					
	Constant	*ln* Po	*ln* P_G	*ln* P_{EL}	*ln* (y_E / P_E)	T
Gasoline/ Fuel oil (O)	0.6690	0.1719	-0.0634	-0.1085	0.0288	-0.0041
	(0.0454)	(0.0835)	(0.0131)	(0.0306)	(0.0791)	(0.0012)
Natural Gas (G)	0.1683	-0.0634	0.0797	-0.0163	0.0029	-0.0012
	(0.0186)	(0.0131)	(0.0172)	(0.0184)	(0.0248)	(0.0005)
Electricity (EL)	0.1627	-0.1085	-0.0163	0.1248	-0.0317	0.0053
	(0.0473)	(0.0306)	(0.0184)	(0.0438)	(0.0825)	(0.0013)

Note: Standard errors are in parentheses. Convergence achieved after five iterations. The logarithm of the likelihood value is 370.50.

Table-3. Elasticities Estimates of Commodity and Leisure Demand

	Own-price elasticity		Income (or expenditure) elasticity
	Uncompensated	Compensated	
Non-energy products (N)	-0.7155	-0.1421	1.0126
	(0.0232)	(0.0198)	(0.0103)
Energy products (E)	-0.1517	-0.1157	0.6215
	(0.0914)	(0.0862)	(0.0738)
Leisure (R)	-0.2441	-0.0896	1.0762
	(0.1144)	(0.0554)	(0.0114)

Note: Standard errors are in parentheses.

Table-4. Elasticities Estimates of Individual Types of Energy

	Own-price elasticity		Total energy expenditure elasticity
	Uncompensated	Compensated	
Gasoline/ Fuel oil (O)	-0.1659 (0.0243)	-0.1257 (0.0169)	1.0771 (0.0078)
Natural Gas (G)	-0.0598 (0.0311)	-0.0461 (0.0256)	1.0337 (0.0026)
Electricity (EL)	-0.0801 (0.0134)	-0.0611 (0.0207)	0.8179 (0.0354)

Note: Standard errors are in parentheses.

Table-5. Elasticities Estimates of Labor Supply

	Price elasticity		Income elasticity
	Uncompensated	Compensated	
Labor supply (L)	0.0819 (0.0384)	0.2365 (0.0575)	-0.3613 (0.0038)

Note: Standard errors are in parentheses.

The consumer behavior model which has been used in this study incorporates the nonseparable labor supply effects from individual types of commodity demands. Thus, the energy demand and economic policy impacts evaluated from the consumer behavior model in this study would be distinct from those from empirical energy demand studies which do not take into account the interactions between individual types of energy, other goods, and labor supply.

V. WELFARE EFFECTS OF ENERGY TAXATION

In general, taxes create deadweight losses by distorting economic behavior. In this case, the welfare cost of taxation measures the value of the opportunities that are lost when taxes divert economic resources from their best uses. The behavioral changes caused by taxation can occur, for example, at willingness to work and choices among different consumption goods. In the spirit of Hicksian equilvalent variation, the deadweight loss, as a measure of money value of the behavioral changes, can be considered to be the amount in excess of the revenue collected that consumers would be willing to pay to shift from distortionary taxation to lump sum taxation.[17]

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[17] This was originally defined by Mohring (1971) and discussed more in Auerbach (1985).

Let W^0 and W^1 be the potential level of social welfare in our representative consumer economy before and after the imposition of taxes, respectively. The monetary equivalent social welfare change, caused by changes in prices from the pre-tax level p^0 to the post-tax level p^1, can be given in terms of difference in the levels of full expenditure function $F(p^1, W^1) - F(p^0, W^1)$, evaluated at the same level of post-tax utility for each period. Then, the measure of aggregate deadweight loss from taxation is defined as:

$$DWL(p^1, p^0, W^1) = F(p^1, W^1) - F(p^0, W^1) - R(p^1, F) \tag{8}$$

where R is the tax revenue collected when prices are at p^1 and the consumer's full income level equals F. As noted in Mohring (1971), Auerbach (1985) and Slesnick (1991), this measure of the aggregate deadweight loss is the amount, in excess of the compensated tax revenue collected, the consumer would be willing to pay at existing prices to forgo all taxes. From (9), the commodity-specific marginal deadweight loss (attributable to the taxation of the *i*th commodity) is also defined to be the additional excess burden that results from increasing tax revenue by a dollar by raising the tax rate on the *i*th commodity:

$$MDWL_i(p^1, p^0, W^1) = \frac{\partial DWL(p^1, p^0, W^1)/\partial t_i}{\partial R(p^1, p^0, W^1)/\partial t_i} \tag{9}$$

One of the main motivations for estimating complete consumer demand system is to facilitate welfare analysis. Estimates of the demand system parameters in previous section enables us to evaluate the level of aggregate and marginal deadweight loss due to gasoline and labor taxation over the period from 1959 to 1999 in the U.S. economy.[18] The difference in the deadweight loss, abstracting from the marginal environmental damages from gasoline consumption, of gasoline and labor taxation would critically determine the scope for revenue neutral tax reforms from labor tax to gasoline tax.

Time series data on gasoline tax rates are obtained by taxes on "Motor Fuel" from various issues of the Tax Foundation's *Facts and Figures on Government Finance* that includes the federal, state and local levels for the U.S economy. However, it seems not simple to estimate the labor tax. To approximate the average rate of labor taxation in the U.S., this study followed the procedure in Mendoza et al. (1994) using various issues of the OECD's Revenue Statistics and National Accounts.[19]

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[18] The 'gasoline tax' in this study really represents a more general tax on all petroleum-based fuels used in transportation, including jet and diesel fuels.

[19] Here, the average rate of tax on labor income (t_L) is given by:

$$t_L = (t_h{*}W+2000+5000) / (W+2200),$$

where t_h is average personal income tax rate, W is wages and salaries, 2000 is national insurance contributions, 5000 is taxes on goods and services, netting out excises on gasoline and other fuels, and 2200 is employer's contribution to national insurance. See, for a detail, Mendoza et al. (1994).

Table-6. Effective Tax Rates for Gasoline and Labor Income (in Percent)

Year	Gasoline*	Labor Income**
1959	32.50	23.68
1960	35.32	24.42
1961	38.48	24.21
1962	38.72	24.60
1963	39.07	25.19
1964	39.58	23.90
1965	38.30	23.40
1966	37.86	25.86
1967	37.33	26.54
1968	37.09	27.02
1969	37.22	28.24
1970	39.11	26.46
1971	39.10	26.00
1972	39.81	27.41
1973	37.49	27.95
1974	30.34	28.59
1975	27.70	26.89
1976	26.26	27.52
1977	25.44	27.92
1978	24.60	28.70
1979	19.83	29.56
1980	15.55	28.93
1981	13.94	28.84
1982	15.53	28.23
1983	16.83	27.68
1984	22.78	27.71
1985	24.27	29.75
1986	30.06	28.17
1987	31.03	28.40
1988	32.43	28.38
1989	30.33	29.04
1990	27.56	30.27
1991	33.30	30.69
1992	36.57	30.45
1993	37.24	31.03
1994	42.16	30.71
1995	40.80	31.10
1996	36.93	31.61
1997	37.59	32.12
1998	44.26	32.65
1999	42.59	33.17

Notes: * The tax rate is assumed to be the ratio of the total motor fuel tax paid to aggregate motor fuel expenditure.

** Assuming that both earned and unearned income is taxed at similar rates, the effective (average) labor income tax rate incorporates national insurance contribution, even though excises on gasoline is solely netted out of taxes on goods and services.

Sources: *Facts and Figures on Government Finance*, Tax Foundation; *NIPA* (Table 2.8M and Table 2.9M), BEA; and *Revenue Statistics* and *National Accounts*, OECD.

The time series data on the level of gasoline and labor taxation in the econometric consumer behavior model are presented in Table-6. According to Table-6, due to the large increase in the before-tax price of the two oil crises, the tax rate on gasoline dramatically declines over the period from 1973 to 1982. However, it increases steadily until 1999, reflecting a greater concern of environmental problems. Labor income tax burden appears to be relatively stable but it follows a slightly increasing trend over the sample period.

In evaluating the welfare effects of taxation, the following three things in this study should be kept in mind. First, since leisure is not separable from the goods consumption, labor and gasoline taxation can affect each other in the model, which is distinct from most of the previous studies that assumes separability between goods and leisure.[20] Second, however, producer prices in this model are assumed fixed and thus the general equilibrium effects are ignored due to abstracting from the producer behavior. Third, in this study, the measures of aggregate deadweight loss attributable to the existing tax structure should be interpreted as an indicator of loss in allocative efficiency in our representative economy rather than a true measure of social welfare.

To discuss the environmental performance of energy taxes, it is of great importance to know how these taxes will affect the demand for the goods that generate pollutions in their use. Gasoline is a typical example of the pollution-generating consumption goods. The price increase for gasoline due to taxation has an effect on not only the gasoline itself but also on all other goods to consume, taking into account all own- and cross-price effects.

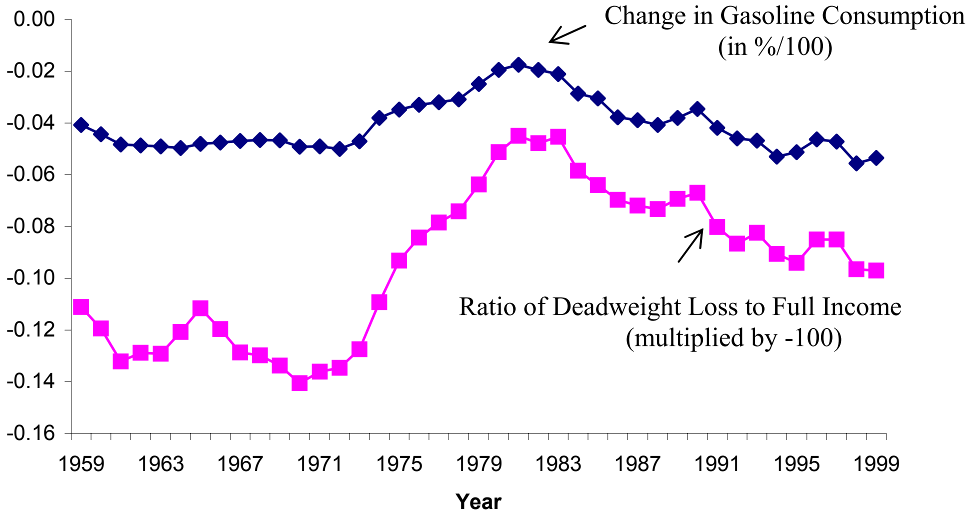

Figure-1. Effects of Gasoline Tax on Gasoline Consumption and Welfare

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[20] In this case, the impact of (labor) income taxation on the deadweight loss due to commodity-specific taxation can be taken into account.

Figure-1 illustrates the effects of gasoline taxation on gasoline consumption and welfare spanning over the period from 1959 to 1999 without any tax replacement. The horizontal axis represents the years within the sample period. On the vertical axis, under the actual tax regime, we have the gasoline consumption change in terms of percent/100. Also, the deadweight cost of gasoline taxation, as a welfare index, is presented in terms of monetary value compared to the full income level.

In Figure-1, we can see that the actual gasoline tax has led to a decrease of the gasoline consumption by approximately 4 percent over the period from 1959 to 1999. At the same time, the deadweight loss caused by the tax has occupied around 0.08 percent of the full income with a similar trend over the sample period. The measures of aggregate deadweight loss indicates the monetary measures of the changes in social welfare that would result if the existing gasoline tax is replaced with an equal yield lump sum tax. In particular, the deadweight loss per full income significantly decreases over the period from 1973 to 1981. The reason for this is due to a higher decline in the existing tax rate, reflecting the large increase in the pre-tax price of crude oil price experienced over the same period. However, it also corresponds to a smaller potential for the decrease of gasoline consumption in the environmental point of view.[21]

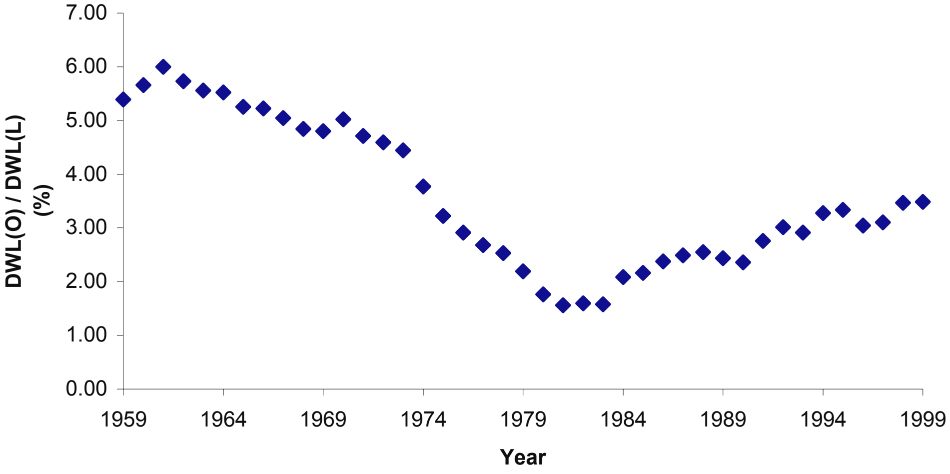

Figure-2. Ratio of Deadweight Cost of Gasoline Tax to that of Labor Tax

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[21] The principle dividend of gasoline taxation could remain the environmental dividend. In this case, the economic performance of gasoline taxation should involve the welfare benefits attributable to decreases in gasoline consumption. This consideration would be of critical importance if the major purpose of energy-related taxation entails the improvement of environmental quality through the internalization of environmental costs.

The various measures of deadweight loss attributable to the existing gasoline and labor taxation, as defined in (8) and (9), are estimated for the sample period 1959-1999 and are reported in Table-7. The total deadweight loss from the existing gasoline tax ranges from \$397.9 millions in 1959 to \$7162.8 millions in 1999, while the total deadweight loss from labor tax ranges from \$7381.5 millions in 1959 to \$205592.1 millions in 1999. These levels can be considered as the additional tax revenues that could be collected with no social welfare loss if the existing taxes are replaced by nondistortionary lump sum taxation. For the sake of comparison, the ratio of deadweight loss from gasoline tax to that of labor tax is also presented in Figure-2. This ratio ranges from a minimum of 1.6 percent in 1981 to a maximum of about 6 percent in 1960.

Similarly, in Table-7, the average deadweight loss represents the monetary value of the efficiency loss per dollar of tax revenue collected. In the case of gasoline, it has a minimum level of 0.0656 in 1981 when the lowest tax rate, 13.9 percent, are imposed during the sample period. The average loss per dollar collected from gasoline tax has an increasing trend in recent years. For labor taxation, the average deadweight loss has a minimum of 0.1122 in 1960 and a maximum of 0.1471 in 1983. For the marginal deadweight loss of the existing gasoline tax regime, a dollar increase in tax revenue induces a positive range of changes in total deadweight loss from 0.1493 to 0.2521. The marginal deadweight loss of labor tax ranges from 0.1786 to 0.2610. In most years of the sample period, the measures of marginal deadweight loss of labor tax are relatively large compared to those of gasoline tax. This implies a larger efficiency gain in the case of labor taxation in shifting from the existing distortionary taxation to lump sum taxation.[22]

However, as mentioned before, these results do not tell the whole story of the relationship between tax reform and social welfare. It should be noted that the deadweight costs of gasoline and labor taxation are not accounted for solely by the partial equilibrium approaches. In this study, we are abstracted from many other considerations. Much of these welfare costs due to taxation could be more closely explained in the context of general equilibrium approaches, incorporating the dynamics of capital markets, the flexibility and responsiveness of the whole economy, the openness of the economy, imperfect factor mobility, other pre-existing distortions, and distributional considerations, and so on.

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[22] In theory, the welfare effects of reducing one tax at the expense of raising another tax, holding total tax revenues constant, depend critically on the relative magnitude of marginal deadweight loss of each of these taxes. If there exists wide differences between the marginal deadweight loss burdens of gasoline and labor taxes, we may have a scope for tax reform from one to the other so as to enhance economic welfare.

Table-7. Deadweight Loss of Gasoline and Labor Taxes – Actual Tax Regime

	Deadweight Loss of Gasoline Tax			Deadweight Loss of Labor Tax		
Year	Total (millions $)	Average	Marginal	Total (millions $)	Average	Marginal
1959	397.9	0.0799	0.1676	7381.5	0.1141	0.1798
1960	445.6	0.0796	0.1577	7871.2	0.1122	0.1786
1961	511.1	0.0843	0.1539	8523.1	0.1190	0.1785
1962	527.8	0.0833	0.1543	9211.6	0.1185	0.1796
1963	557.3	0.0841	0.1530	10029.5	0.1196	0.1801
1964	560.2	0.0799	0.1535	10138.6	0.1185	0.1826
1965	558.3	0.0760	0.1522	10626.4	0.1175	0.1851
1966	649.0	0.0828	0.1507	12427.3	0.1129	0.1827
1967	746.3	0.0912	0.1514	14787.0	0.1219	0.1832
1968	829.6	0.0962	0.1555	17131.0	0.1257	0.1852
1969	928.7	0.0997	0.1548	19337.6	0.1234	0.1852
1970	1059.7	0.1029	0.1531	21101.6	0.1344	0.1878
1971	1113.9	0.1028	0.1571	23633.1	0.1438	0.1915
1972	1204.6	0.1027	0.1589	26232.3	0.1379	0.1923
1973	1261.3	0.0978	0.1522	28381.7	0.1316	0.1941
1974	1191.4	0.0893	0.1493	31581.0	0.1306	0.1988
1975	1130.7	0.0848	0.1649	35095.4	0.1447	0.2054
1976	1138.0	0.0815	0.1727	39081.9	0.1413	0.2089
1977	1181.5	0.0801	0.1825	44033.1	0.1409	0.2124
1978	1250.8	0.0825	0.1994	49450.4	0.1363	0.2149
1979	1204.3	0.0753	0.1921	54963.8	0.1311	0.2201
1980	1078.9	0.0679	0.2033	61221.3	0.1354	0.2267
1981	1042.5	0.0658	0.2209	66871.1	0.1346	0.2313
1982	1196.0	0.0709	0.2370	75041.9	0.1464	0.2337
1983	1237.0	0.0689	0.2521	78293.1	0.1471	0.2362
1984	1738.9	0.0704	0.2078	83380.6	0.1421	0.2364
1985	2064.2	0.0768	0.2078	95518.0	0.1410	0.2398
1986	2410.6	0.0878	0.2384	101329.8	0.1491	0.2379
1987	2666.2	0.0890	0.2298	107085.6	0.1456	0.2391
1988	2942.8	0.0913	0.2330	115393.8	0.1458	0.2406
1989	2978.8	0.0902	0.2337	122325.3	0.1424	0.2436
1990	3063.4	0.0925	0.2318	129927.3	0.1365	0.2475
1991	3805.5	0.0995	0.2218	137848.2	0.1386	0.2476
1992	4351.5	0.1016	0.2102	144344.5	0.1381	0.2482
1993	4352.4	0.0979	0.2159	149359.3	0.1349	0.2506
1994	5051.2	0.0978	0.1986	154134.1	0.1340	0.2501
1995	5534.3	0.1065	0.1946	165829.0	0.1360	0.2518
1996	5260.2	0.1019	0.1954	172872.2	0.1329	0.2557
1997	5532.9	0.1028	0.1947	178276.2	0.1272	0.2574
1998	6654.7	0.1174	0.2084	191953.8	0.1257	0.2573
1999	7162.8	0.1178	0.1951	205592.1	0.1247	0.2610
Average	-	0.0891	0.1882	-	0.1325	0.2175

VI. SUMMARY AND CONCLUSIONS

This paper was motivated by the need to provide more reasonable estimates for the welfare cost of environmental tax reform. Unlike most previous studies that empirically evaluate the deadweight loss of taxation, the model employed here considers explicitly the joint allocation of leisure and commodity demands where the wage rate plays a role both as a form of income and as the price of leisure time.

In Section V, we see that the energy-related tax such as gasoline tax could contribute to energy conservation for the U.S. economy. The estimated results of the consumer behavior model indicate that for the U.S. economy, the existing gasoline tax regime has induced a decrease of gasoline consumption by approximately 4 percent over the period from 1959 to 1999. The deadweight loss caused by the gasoline tax accounts for about 0.08 percent of the consumer full income over the sample period. Moreover, in most years of the sample period, the measures of marginal deadweight loss of gasoline taxation (sample average 0.1882) are relatively small compared to those of labor taxation (sample average 0.2175). This implies a larger efficiency gain in the case of labor taxation in shifting from the existing distortionary taxation to lump sum taxation. These results might suggest the modest possibility of social welfare gains from tax reforms that shift some of the burden of taxation off labor onto energy such as gasoline, taking into account the relationship between energy use and environmental benefits.

Nonetheless, some limitations to this study deserve mention. In estimating measures of deadweight loss due to taxation, first, this study assumes a representative consumer and thus uses only the aggregated time series data with the cost of unknown aggregation biases over consumers. The non-energy products in the model are also highly aggregated, neglecting the possibilities that some commodities such as housing, transportation, and other capital services are closely correlated to individual types of energy or non-market leisure time. Second, the model used is static, ignoring the inter-temporal choice by consumers and the dynamics of capital markets. In other words, the allocation of capital is frozen during each year over the sample period. The deadweight loss of energy taxation would also crucially depend on the relative preexisting tax distortions of labor and capital. The tax burden from energy-related taxes might interact more with the relatively overtaxed capital market in the U.S. economy. For instance, if the energy sector is more capital intensive, environmentally-targeted tax policies could shift more of the burden toward capital. Finally, the analysis in this paper does not incorporate the flexibility and responsiveness of the whole economy and any distributional considerations, which would still affect monetary measures of welfare costs due to energy taxation. This paper could be extended to consider these issues with more appropriate data.

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