An Estimate of the Optimal Second-Best Gasoline Tax Considering Both Efficiency and Equity

Roberton C. Williams III
University of Texas at Austin and NBER
rwilliam@eco.utexas.edu

June 16, 2004

Key Words: second-best environmental taxes, gasoline tax, nonlinear income tax, demand system

JEL Classification Nos.: H21, H23

Please address correspondence to Roberton Williams, Department of Economics, University of Texas, Austin, TX 78712, 512-475-8522. E-mail: rwilliam@eco.utexas.edu. I thank participants in the 2004 AERE Summer Workshop for their helpful comments and suggestions. In addition, I thank Sarah West for her collaboration with me on earlier work that led to this paper, and Chris Lyddy, Trey Miller and Jim Sallee for their excellent research assistance on that work. I am grateful for support from the William and Flora Hewlett Foundation.

An Estimate of the Optimal Second-Best Gasoline Tax Considering Both Efficiency and Equity

Abstract

This study investigates the optimal taxation of gasoline in a setting with pre-existing taxes and heterogeneous consumers, taking into account both equity and efficiency considerations. It uses data from the Consumer Expenditure Survey to estimate a demand system for leisure, gasoline, and other goods, and then incorporates those estimates into a model of optimal income and commodity taxation to calculate the optimal second-best gas tax rate.

All prior work on second-best optimal gas taxes–and the vast majority of the second-best environmental tax literature as a whole–has assumed a representative agent, producing potentially misleading conclusions. Gasoline is a necessity good, which, in a representative agent model, implies a higher second-best optimal tax. But taxing necessities has harmful distributional effects, which a representative-agent model cannot capture. This study calculates an optimal policy that takes into account both efficiency and distributional concerns.

Our model allows consumers to differ both in ability and preferences. Unlike prior applied work in optimal commodity taxation, this study uses micro data, making it possible to relax assumptions of separability and homotheticity. In addition, rather than assuming a particular social welfare function, it incorporates equity considerations by solving for the optimal tax rate under the constraint that the tax change cannot make any income group worse off.

The results suggest that the optimal gasoline tax rate exceeds the marginal damage from gasoline use, though distributional concerns cause this tax rate to be substantially less than a representative-agent model would suggest.

I. Introduction

Distributional concerns play an important role in setting environmental taxes. Most studies suggest that environmental taxes are at least somewhat regressive.[1] This is particularly true for gasoline. Many studies have shown that gasoline taxes are strongly regressive,[2] and this regressive impact is frequently raised as an argument against raising gasoline taxes, even though existing tax rates are well below the marginal external damage from gasoline use. Despite this, most work on optimal environmental policy ignores distributional considerations, focusing exclusively on efficiency.

This paper estimates the optimal tax on gasoline in a second-best setting with a pre-existing distortionary income tax. It models a set of heterogeneous consumers and a redistributive nonlinear income tax, thus making it possible to consider distributional as well as efficiency considerations in setting the gasoline tax. It uses data from the Consumer Expenditure Survey and other sources both to estimate the household utility functions and to evaluate the optimal gasoline tax in this model.

An extensive recent literature studies the problem of setting corrective taxes in the presence of pre-existing distortionary taxes in other markets.[3] However, the vast majority of this literature uses representative-agent models, and thus cannot consider distributional objectives in setting externality taxes. A handful of papers consider distributional objectives as well, using a model with heterogeneous consumers and a nonlinear tax system, though almost all of these are exclusively theoretical.[4]

An exception is Cremer *et al*. (2003), which calculates the optimal energy tax for France, in a model with four household types and a redistributive nonlinear income tax system. The present paper differs from Cremer *et al*. in several respects. First, it examines gasoline taxes in the United States rather than a broad-based energy tax in France. Second, it uses a micro-level data set of individual households, rather than macro-level aggregates. This makes it possible to estimate a more flexible, nonseparable functional form for utility and to have differences in preferences across household types without assuming utility is homothetic. Finally, it incorporates equity considerations without relying on an arbitrary social welfare function.

This paper models an economy with a continuum of households, who may differ in endowments, earning ability, or preferences. It solves for the optimal gasoline tax, subject to the constraint that any change in taxes must be distribution-neutral: that is, the progressivity of the income tax must adjust to offset the distributional effects of the gasoline tax. In this setting, the

---

[1] See Poterba (1991), for example, which finds that expenditure shares for polluting goods generally fall as income rises, suggesting that environmental taxes will be regressive.

[2] For example, see Kayser (2000), Sevigny (1998), Sipes and Mendelsohn (2001), and Walls *et al.* (1994). West and Williams (2004b) finds that this regressive effect can be more than offset by returning the gasoline tax revenue as a lump sum transfer, but only briefly discusses the efficiency effects of such a transfer, and does not estimate the optimal tax on gasoline.

[3] See Goulder (2002) for a survey of this literature.

[4] See, for example, Kaplow (1996), Mayeres and Proost (1997), Pirttilä and Tuomala (1997), and Cremer *et al*. (1998). Mayeres and Poost (2001) examines distributional issues in an applied framework, but does not allow nonlinear income taxes, thus removing an important tool that the government can use to achieve distributional objectives.

optimal gasoline tax depends on the marginal damage from gasoline, the degree of nonseparability between labor and gasoline in utility, the differences in preferences across individual types, and the level of pre-existing tax distortions.

The paper follows West and Williams (2004a) in its approach to estimating the household utility functions, using the same data set and demand system, though the approach it uses to estimate the optimal tax rate differs substantially from that paper, which ignored distributional considerations entirely. This paper uses the 1996 through 1998 Consumer Expenditure Surveys, which provide detailed data on household expenditures including gasoline expenditures, and on each individual's wages and working hours. These data are merged with state-level price information from the American Chambers of Commerce Researchers' Association (ACCRA) cost of living index. We use the National Bureau of Economic Research's (NBER) TAXSIM model to calculate marginal and average tax rates of each worker. The resulting data set thus includes quantities and after-tax prices for all goods and leisure.

Most commonly used functional forms impose separability, homotheticity, or both; the linear expenditure system (LES), for example, imposes additive separability, while a constant elasticity of substitution (CES) utility function is both separable and homothetic. To resolve this problem, this paper uses the Almost Ideal Demand System (AIDS), first derived by Deaton and Muellbauer (1980). The advantages of this system are well-known: it gives a first-order approximation to any demand system, satisfies the axioms of choice exactly, is simple to estimate, and does not impose either separability or homotheticity. We estimate our demand system separately for one-adult households and for two-adult households with one female and one male.

Most prior work that considers equity issues in setting optimal taxes assumes a particular social welfare function. This is fine for purely theoretical papers, but presents problems for applied work. The optimal taxes in such models can be quite sensitive to the particular function assumed, which is necessarily quite arbitrary. This paper resolves this problem by assuming that any change in the tax system must be distribution-neutral: the distributional effects must be offset by a compensating change in the income tax.[5] The optimal tax is then the Pareto-optimal rate, the rate at which any change in the tax will necessarily make some income group worse off, even when accompanied by an appropriate change in the tax schedule. This makes it possible to take distributional effects into account in calculating the optimal tax rate, but without having to assume a social welfare function.

The paper finds that the optimal gasoline tax in this model is roughly 91 cents per gallon, which is nearly 20% above the marginal damage of 77 cents per gallon (taken from the survey in Parry and Small, 2004). This difference primarily reflects the nonseparability in utility; gasoline more complementary to leisure than it would be if utility were separable. Thus, the combination of a gas tax increase and compensating cut in the income tax leads to an increase in labor supply, which ameliorates the pre-existing tax distortion in the labor market. This extra efficiency gain implies a higher optimal tax on gasoline.

However, the estimates are lower than a representative agent model would imply. West and Williams (2004a) use the same data set and econometric approach as this paper, but ignore

[5] This approach can be seen as an extension of the approach used in Kaplow (2004a and b).

distributional considerations in solving for the optimal tax, and get an optimal rate of $1.03 per gallon, substantially higher than this paper's result. The difference arises because of distributional concerns; gasoline is a necessity, and thus taxing it is regressive. That regressivity can be offset by making the income tax system more progressive, but this comes at a substantial efficiency cost, thus lowering the optimal tax rate.

The second section of this paper presents a theoretical model of the tax system and derives a formula for the optimal gasoline tax. The third section explains the demand system, data set, and econometric approach. The fourth section then estimates optimal tax rates. The final section concludes.

II. A Theoretical Model

This section presents an analytical model of an economy with a tax system consisting of an environmental tax and a flexible nonlinear income tax, and uses it to derive an expression for the optimal environmental tax rate. The model's structure is similar to that in West and Williams (2004a), though the government's objective and tax instruments differ. In that model, the government simply maximizes efficiency, and tax changes are constrained to be proportional to income, whereas in the model presented here, the government also considers equity, and has full flexibility to adjust the nonlinear income tax schedule.

A. Model Structure

The economy consists of a continuum of households, who may differ in preferences, endowments, or both. The utility function for household *h* is given by

(1) $U^h\left(\mathbf{l^h}, C^h, D^h, G\right) \phi\, \phi^h(D)$,

where $\mathbf{l^h}$ is a vector that represents leisure for each adult individual in the household, C^h is the household's consumption of a clean (i.e., nonpolluting) consumer good, D^h is consumption of a dirty (i.e., polluting) good, and *G* is the level of a government-provided public good.[6] The household suffers disutility ϕ^h from an externality caused by the economy-wide total consumption of the dirty good ($D = \int_h D^h$). Individual *i* in household *h* faces the time constraint

(2) $\bar{L} = L^{hi} + l^{hi}$,

where $\bar{L}$ is a fixed time endowment, L^{hi} is hours worked, and l^{hi} is hours of leisure (an element of the vector $\mathbf{l^h}$). The household budget constraint is

(3) $p_C^h C^h + p_D^h D^h = Y^h = \bar{Y}^h - T\left(\bar{Y}^h\right)$,

where p_C^h and p_D^h are the consumer prices of the clean and dirty goods, respectively, Y^h is after-tax income (equal to expenditure), and the function T represents the income tax. Pre-tax income ($\bar{Y}^h$) is given by

(4) $\bar{Y}^h = \bar{I}^h + \sum_i \bar{w}^{hi} L^{hi}$,

where $\bar{w}$ is the pre-tax wage and $\bar{I}$ is pre-tax non-labor income. The after-tax wage is

---

[6] For simplicity in notation, household-specific functions and quantities are denoted with a single superscript h, even though the household continuum may be multi-dimensional.

(5) $$w^{hi} = \overline{w}^{hi}\left[1'\ T'\left(\overline{Y}^h\right)\right],$$

The consumer price for the dirty good is

(6) $$p_D^h = \overline{p}_D^h + \tau_D,$$

where $\overline{p}_D$ is the producer price and τ_D is the tax rate per unit. The clean good is untaxed, so its consumer price equals its producer price ($\overline{p}_C$). Production of each good exhibits constant returns to scale. Non-labor income is derived from ownership of a fixed factor that is a perfect substitute for labor.[7] Markets are perfectly competitive, implying that the price of each good equals marginal cost, and the price of each input equals its marginal product. These assumptions imply that the pre-tax wage and all producer prices are exogenously fixed and that the aggregate production constraint is

(7) $$\int_h \int \overline{I}^h + \int_i \overline{w}^{hi} L^{hi} \int = \overline{p}_G G + \int_h \left(\overline{p}_C^h C^h + \overline{p}_D^h D^h\right),$$

where $\overline{p}_G$ is the producer price of the public good. The government's budget constraint is

(8) $$\overline{p}_G G = R \int \int_h \left[\int_D^h D^h + T\left(\overline{Y}^h\right)\right],$$

where R is government revenue, which must equal spending on the public good.

Each household chooses its consumption of each good and labor supply for each individual in order to maximize utility (1), subject to its time constraints (2) and budget constraint (3), taking the income tax, after-tax prices and wages, and the level of pollution as given.[8] The dual to this maximization problem implicitly defines the expenditure function

(9) $$E^h\left(U^h, p_C^h, p_D^h, \mathbf{w^h}, G\right) = p_C^h C^{h*} + p_D^h D^{h*} + \sum_i w^{hi} l^{hi*}.$$

This is the minimum level of full expenditure (expenditure on goods plus implicit expenditure on leisure) necessary to achieve a utility of U^h for a given set of after-tax prices and wages and a given quantity of the public good.[9] In this expression, C^{h*}, D^{h*}, and l^{hi*} are the expenditure-minimizing quantities of the consumption goods and leisure.

B. Solving for the Optimal Tax on the Dirty Good

Now consider a marginal tax reform that consists of a marginal increase in the tax on the dirty good, accompanied by a change in the income tax designed to hold utility constant for each household. Using the expenditure function, the necessary compensation can be expressed as

(10) $$S^h = \frac{\tau E^h}{\tau p_D^h} + \tau^h \frac{dD}{d\tau_D},$$

---

[7] This assumption is clearly unrealistic, but it provides a simple way to introduce non-labor income into the model. For a similar model in which the fixed factor is not a perfect substitute for labor, see Williams (2002). Bovenberg and Goulder (1996) provide a model with non-labor income derived from capital, but it is much more complex than the model used here, and therefore cannot be solved analytically.

[8] If the income tax schedule is not linear, then after-tax wages are not fixed, even for a given income tax schedule, because the marginal tax rate varies along the tax schedule. For marginal changes, assuming that households take after-tax wages as given is equivalent to taking a local first-order approximation to the tax schedule.

[9] Note that this expenditure function ignores the disutility from the externality.

where S^h is the marginal decrease in income tax paid by household *h*, holding the household's pre-tax income constant, and θ^h is the marginal damage to the household from the externality, in monetary terms. This is given by

(11) $$\partial^h \; \partial \; \partial\partial \frac{\partial E^h}{\partial U^h},$$

The first term in (10) is the amount of compensation necessary to offset the higher price paid for the dirty good. Shephard's Lemma gives $\frac{\partial E^h}{\partial p_D^h} = D^h$, so this term equals the household's consumption of the dirty good. The second term is the value to the household of reducing the externality, equal to the marginal damage from the externality times the change in total consumption by all households of the dirty good as a result of the tax shift. For any given household, expression (10) could be positive or negative, depending on the relative magnitudes of the two terms. For a household that puts a high value on environmental quality, but consumes little of the dirty good, there will be a net benefit from raising the dirty good tax, and thus the compensation will be negative. The opposite would be true for a household that puts little value on the environment and consumes a lot of the dirty good.

However, it may not be possible to achieve exactly this level of compensation for every household, because any change in the income tax schedule will provide the same compensation to all households with a given pre-tax income. If households differ in only one dimension, and preferences and the tax schedule are such that there is no bunching of incomes (i.e., that in equilibrium there is a one-to-one mapping from household type to pre-tax income), then all households with the same income will also have the same consumption of the dirty good, and the same marginal valuation of environmental quality. In this case, the necessary compensation from expression (10) would be the equal for all households at a given income level, and thus an appropriate change in the income tax schedule could exactly compensate each household. But if either of these assumptions fails to hold, then in general there will be households that have the same income, but require different levels of compensation.

Consider, therefore, a marginal change in the income tax schedule that compensates the average household at any given income level for a marginal increase in the dirty good tax. This change, as a function of pre-tax income, is given by

(12) $$F(\bar{Y})\,\theta\,\theta\frac{dT(\bar{Y})}{d\theta_D} = \tilde{D}(\bar{Y}) + \tilde{\theta}(\bar{Y})\frac{dD}{d\theta_D}$$

where the function $\tilde{D}(\bar{Y})$ is the mean of D^h over households with pre-tax income $\bar{Y}$, and $\tilde{\theta}(\bar{Y})$ is the analogous function for θ^h.

Taking a total derivative of the government budget constraint (8) with respect to the dirty good tax and substituting in the total derivative of pre-tax income (4) give an expression for the change in government revenue from the combination of a marginal increase in the dirty good tax and compensating marginal change in the income tax schedule:

(13) $$\frac{dR}{d\int_D} = \int_h \int D^h + \int_D \frac{dD^h}{d\int_D} \int \; F(\bar{Y}^h) + T\int(\bar{Y}^h)\int_i \; \bar{w}^{hi}\frac{dL^{hi}\int}{d\int_D}\int.$$

We can now use this expression to solve for the optimal dirty good tax. Start by considering the case in which the necessary compensation from expression (10) is equal for all households at a given income level, and thus a change in the income tax schedule can exactly compensate all households. If expression (13) is positive, then the government can raise the dirty good tax, compensate all households, and still have additional revenue left over. The leftover revenue could then be used for an additional lump-sum cut in taxes at all income levels, which would benefit all households.[10] Thus, the government can achieve a pure Pareto improvement by increasing the dirty good tax and making an appropriate change in the income tax schedule. Conversely, if expression (13) is negative, then the government can lower the dirty good tax, exactly compensate all households, and have revenue left over. In this case, lowering the dirty good tax can produce a pure Pareto improvement when combined with an appropriate change in the income tax schedule.

The Pareto-optimal tax rate on the dirty good is thus the rate at which the marginal revenue from the dirty good tax exactly equals the marginal cost of compensating households. From this point, any change in the dirty good tax will necessarily make some households worse off, even when accompanied by an appropriate change in the income tax schedule.

Now consider the general case in which the necessary compensation from expression (10) is not equal for all households at a given income level. In this case, the logic is exactly the same, but the tax changes no longer yield a Pareto improvement: at any given income level, the change in the income tax schedule will overcompensate some households and undercompensate others.[11] Instead, they yield what Ng (1984) termed a *quasi-Pareto* improvement. That is, for all levels of income, the average household with that income is made better off, though particular households may be made worse off. This represents an intermediate case between a Pareto improvement, in which all households are made better off, and a Kaldor-Hicks improvement, in which the economy-wide average household is made better off, but the average household at any given level of income may be worse off. The quasi-Pareto concept is very useful, because Pareto improvements are almost never possible except in highly stylized and unrealistic models.

The optimal tax rate in this general case is still the rate at which the marginal revenue is just enough to finance the compensating income tax change. But in this case it is the quasi-Pareto optimal rate. To find an expression for this optimal rate, set expression (13) equal to zero, substitute in (12) and the equation for the after-tax wage (5), and solve for τ_D, recognizing that the integral of $\tilde{D}\left(\bar{Y}^h\right)$ equals the integral of D^h. This yields

---

[10] It is theoretically possible for this additional tax cut to make households worse off. If the dirty good is normal, the income effect from the additional cut will increase consumption and thus increase damage from the externality. If that increase in damage exceeds the amount of the additional cut, then households will actually be worse off. But this seems highly unlikely to occur in practice.

[11] It may still be possible to get a pure Pareto improvement from an arbitrary starting point by changing the dirty good tax and the income tax schedule, if the leftover revenue from (13) is sufficiently large relative to the heterogeneity in (10) at a given level of income. In this case, even though the change in the tax schedule given by (12) would undercompensate some households, the additional gain made possible by the leftover revenue would be enough to make those households better off. But this cannot occur in the neighborhood of τ_D^*, because the leftover marginal revenue (13) goes to zero as τ_D goes to τ_D^*.

(14) $$\tau_D^* = \theta + \frac{\sum_h \sum_i \left(\bar{w}^{hi} - w^{hi}\right)\frac{dL^{hi}}{d\tau_D}}{-\frac{dD}{d\tau_D}},$$

where θ is the marginal external damage from the dirty good, given by

(15) $$\theta = \sum_h \theta^h .$$

In a partial-equilibrium model, the optimal dirty good tax would simply equal marginal external damage, as shown by Pigou (1938). Expression (14) shows that the optimal dirty good tax in the present model is equal to marginal external damage plus a second term that reflects interactions with pre-existing tax distortions. In the absence of such distortions–i.e., if the marginal income tax rate is zero for all households–the second term is equal to zero, and we are back to the partial-equilibrium result.

But when marginal tax rates are not zero, this second term may cause the optimal tax to differ from marginal damage. The reason is the same as in the prior literature on second-best environmental taxation. Tax distortions in the labor market cause the marginal social value of a unit of labor (the value of its marginal product, which equals the pre-tax wage) to exceed the marginal value of a unit of leisure (the value of the marginal utility from leisure, which equals the after-tax wage). Thus, if the marginal tax rate is greater than zero, a policy-induced increase in labor supply will yield a welfare gain, and a decrease in labor supply will yield a welfare loss.

The total derivatives in (14) include the effects of both the increase in the dirty good tax and the compensating income tax change. This doesn't make much difference for the derivative of demand for the dirty good, because the effect of the income tax change will be much smaller than the effect of the dirty good tax, as long as the budget share for the dirty good is relatively small. But this is not true for the derivative of labor supply. Thus it is useful to expand this term as

(16) $$\frac{dL^{hi}}{d\tau_D} = \frac{\partial L^{hi}}{\partial p_D^h} + F'\left(\bar{Y}^h\right)\sum_j \bar{w}^{hj}\frac{\partial L^{hi}}{\partial w^{hj}} + \left[F\left(\bar{Y}^h\right) - D^h\right]\frac{\partial L^{hi}}{\partial Y^h},$$

where $\frac{\partial L^{hi}}{\partial p_D^h}$ and $\frac{\partial L^{hi}}{\partial w^{hj}}$ are compensated derivatives, and $\frac{\partial L^{hi}}{\partial Y^h}$ is the derivative with respect to lump-sum after-tax income. The first term in (16) is the substitution effect from the increase in the price of the dirty good caused by the increased dirty good tax. The second term is the substitution effect from the change in the income tax schedule. And the third term is the sum of the income effects for the two changes.

It is also useful at this point to make the simplifying assumption that the average valuation of environmental quality for households at any given income level is proportional to after-tax income. This implies that

(17) $$\tilde{\theta}\left(\bar{Y}\right) = \theta\,\frac{\bar{Y} - T\left(\bar{Y}\right)}{\sum_h Y^h}.$$

To get an expanded expression for the optimal tax, substitute (12) into (14) and then substitute in equations (16) and (17) and the derivatives of those equations. Simplifying the resulting equation gives

$$(18) \qquad \tau_D^* = \frac{\delta}{\mu} + \frac{\sum_h \sum_i \left(\overline{w}^{hi} - w^{hi}\right)\left(\frac{\partial L^{hi}}{\partial p_D^h} + \tilde{D}'\left(\overline{Y}\right)\sum_j \overline{w}^{hj}\frac{\partial L^{hi}}{\partial w^{hj}} + \left[\tilde{D}\left(\overline{Y}^h\right) - D^h\right]\frac{\partial L^{hi}}{\partial Y^h}\right)}{-\frac{dD}{d\tau_D}},$$

where μ is the marginal cost of public funds (MCPF) for a tax increase that is proportional to after-tax income, which is the cost to households of raising a marginal dollar of government revenue. This is given by

$$(19) \qquad \mu = \sum_h Y^h \Bigg/ \sum_h \left\{Y^h - \sum_i \left(\overline{w}^{hi} - w^{hi}\right)\left[\sum_j w^{hj}\frac{\partial L^{hi}}{\partial w^{hj}} + Y^h \frac{\partial L^{hi}}{\partial Y^h}\right]\right\}.$$

The first term in (18) is equal to the optimal dirty good tax found by prior studies of second-best environmental taxation a representative-agent model when utility is both separable and homothetic.[12] These two conditions imply that the optimal tax rate would be zero in the absence of the externality. Thus, any tax on the dirty good in this case is due entirely to the externality.

A similar result appears in this model for the case in which all households have the same preferences and leisure is weakly separable in utility from the two consumption goods–the conditions that imply a zero optimal tax rate when there are no externalities.[13] In this case, the second term in (18) equals zero, and the optimal dirty good tax equals the first term.

The intuition for this result is fairly simple. In this case, the effect on labor supply of the increase in the dirty good tax is exactly offset by the effect of the income tax cut that compensates each income group (ignoring the environmental benefit). But because the tax base for the dirty good tax shrinks as the tax increase, the marginal revenue from the dirty good tax will be less than the cost of the income tax cut by an amount equal to the tax rate times the change in consumption. The optimum is where this net revenue loss exactly equals the revenue from an income tax increase that offsets the benefit to each income group from reducing the externality. And because that tax increase creates a distortion, the optimal tax rate will be slightly less than marginal environmental damage.[14]

The second term in (18) represents the influence of changes in labor supply resulting from the dirty good tax and offsetting income tax cut. If the net effect is to reduce labor supply, this will reduce the optimal tax, whereas an increase in labor supply will increase the optimal tax.

Assuming that leisure is separable in utility affects this term because it implies that

[12] West and Williams (2004a) use a multiple-agent model, but ignore distributional concerns in solving for the optimal tax, and find the same result.

[13] Atkinson and Stiglitz (1976) showed this for an optimal pre-existing nonlinear income tax schedule. Kaplow (2004b) shows that the result still holds even if the income tax schedule is not optimal.

[14] Note that this depends in part on the assumption that the average benefit at a given income level from improved environmental quality is proportional to after-tax income. If the benefit were more than proportional to income, then the compensating income tax change would need to be more progressive and thus would be more distortionary, implying a lower optimal tax. Conversely, if the benefit were less than proportional to income, then the optimal tax would be higher.

(20) $$\frac{\partial L^{hi}}{\partial p_D^h} = \sum \frac{D^h}{Y^h} \varepsilon_{DX}^h \sum_j w^{hj} \frac{\partial L^{hi}}{\partial w^{hj}},$$

where ε_{DX}^h is the expenditure elasticity for the dirty good. Thus, the compensated derivative of labor supply with respect to the price of the dirty good depends on the expenditure elasticity. This implies that the lower the expenditure elasticity, the higher the optimal tax: necessities ($\varepsilon_{DX}^h < 1$) will be taxed more heavily than luxuries ($\varepsilon_{DX}^h > 1$).

But taxes on necessities are generally more regressive than taxes on luxuries. The more regressive is the dirty good tax, the more progressive the compensating income tax change must be. A more progressive income tax cut will increase labor supply by less, implying a lower optimal tax on the dirty good.

If all households have the same preferences, then these two effects exactly offset. But if preferences differ, then the distributional effect of the tax no longer depends only on its income elasticity, but also on how preferences vary over the income distribution. If lower-income households have a stronger taste for the dirty good than do higher-income households–that is, if, given the same income as the high-income households, they would choose to buy more of the dirty good than do the high-income households–then the tax will be more regressive than the expenditure elasticity would indicate. If they would buy less, then the tax will more progressive than the expenditure elasticity would indicate.

III. Demand System Estimation

The formula for the optimal dirty good tax (18) depends on several own-price and cross-price derivatives of labor supply and of demand for the dirty good. This section presents the demand system, data set, and econometric techniques used to estimate these derivatives. This explanation will be relatively brief, however, because the data and demand system estimation are exactly the same as those used in West and Williams (2004a), which provides more detail on the estimation. Indeed, if it were not for the need to derive confidence intervals for the estimated optimal tax rates, it wouldn't be necessary to repeat the demand system estimation at all; one could simply take the estimated utility parameters from that paper.

A. Demand System Specification

This paper uses an Almost Ideal Demand System (AIDS), as proposed in Deaton and Muellbauer (1980), defined over gasoline (the dirty good), leisure, and a composite of all other goods (the clean good). The advantages of the AIDS are well-known: it provides a first-order approximation to any demand system, satisfies the axioms of choice, and does not assume that the utility function is separable or homothetic.

In their budget share form, the AIDS demand equations for gasoline, leisure, and a composite of all other goods for household *h* are:

(21) $$s_j^h = \alpha_j^h + \sum_k \gamma_{jk} \log p_k^h + \beta_j \log\left(y^h / P^h\right) \quad j, k = \text{gasoline, leisure, other goods}; \; h = 1, \ldots, H$$

where α, γ, and γ are parameters to be estimated, and y^h is full income, or total expenditures on gasoline, leisure, and other goods.[15] The price index P^h is approximated by:

(22) $\log P^h \sum\sum_j s_j^h \log\left(p_j^h / \bar{p}_j\right)$.

Demand theory imposes several restrictions on the parameters of the model, including:

(23a) $\sum_j \Sigma_j^h = 1$ (23b) $\sum_j \Sigma_{jk} = 0$ (23c) $\sum_j \Sigma_j = 0$ (23d) $\gamma_{jk} = \gamma_{kj}$.

Under these restrictions, (21) represents a system of demand functions that add up to full income, are homogeneous of degree zero in prices and full income, and satisfy Slutsky symmetry.

B. Data Description and Variable Derivation

The 1996 through 1998 Consumer Expenditure Surveys are the main components of our data. The CEX Family Interview files include the amount spent by each household on gasoline, total expenditures, and a wide variety of household income measures, all for the three months prior to the CEX interview. For each household member, the Member Files include usual weekly work hours, occupation, the gross amount of last pay, the duration of the last pay period, and a variety of member income measures.

We estimate two demand systems: one for one-adult households and the other for two-adult households with one adult male and one adult female (where an adult is at least 18 years of age).[16] The twelve quarters in the 1996 through 1998 Consumer Expenditure Surveys have 4659 one-adult households and 5047 two-adult households under 65 with complete records of the necessary variables. The CEX is a rotating panel survey; each quarter, 20 percent of the sample is rotated out and replaced by new consumer units. We pool observations across quarters. Thus, each household appears in the data one to four times, giving a total of 9725 one-adult observations and 11034 two-adult observations.

Data on gas prices and the price of other goods come from the ACCRA cost-of-living index. This index compiles overall price levels for approximately 300 cities in the United States, along with prices of many specific goods, including the average price of regular, unleaded, national-brand gasoline for each quarter. Since the CEX reports state of residence of each household, and not city, we average the cities within each state to obtain a state gasoline price and state price index for each calendar quarter. Then we assign a gas price and a price index to each CEX household based on state of residence and CEX quarter. For households whose CEX quarters overlap two quarters of price data, we use a weighted average of those two quarters. The price of all other goods is the ACCRA price index divided by 100, and the price index *Ph* is given by equation (22).

---

[15] Please note the slight change in notation. The theory model assigned letters *D, l*, and *C* to the goods for consistency with the prior second-best literature. For compactness, this section uses subscript *j* to index goods. Also note that full income (y^h) as defined here differs from after-tax income (Y^h) as defined in the theory model, in that y^h includes the value of leisure consumed, while Y^h does not.

[16] We exclude households with adults over the age of 65. Less than 5 percent of those over 65 work, and thus non-labor income is very important for this group. We do not realistically model capital income, as discussed in Section II. Thus, excluding those over 65 likely introduces much less error than would including this group.

Full income (y in equation (21) above)) equals the amount spent on gasoline, leisure, and all other goods per week. Since the CEX includes data on labor, but not leisure, we need to specify each person's time endowment. This is assumed to be 90 hours per week, which is the highest number of hours worked by any individual in the sample.

To obtain the price of leisure (the wage) we first calculate the wage net of tax using state and federal effective tax rates from the NBER's TAXSIM model.[17] Since we do not observe wages for individuals who do not work, we follow Heckman (1979) to correct for selectivity bias. See West and Williams (2004a) for more detail on this estimation. We multiply the selectivity-corrected net wage by the number of hours of leisure per week to obtain weekly leisure expenditure.

Table 1 lists summary statistics for the demand system estimation sample, working households that consume gasoline. Households spend about 2 percent of their income on gasoline. One-adult households implicit "spending" on leisure is a bit less than 50 percent of full income for one-adult households and about 55 percent of full income for two-adult households. The average selectivity-corrected net wage is \$8.31 per hour in the one-adult sample, and \$11.02 per hour for men and \$8.60 per hour for women in the two-adult sample.

C. System Estimation and Results

To incorporate the effect that household and individual specific characteristics have on demand, we add a vector of these characteristics, c_r^h, to the constant terms in (21) so that:

(24) $$\zeta_j^h = \zeta_{j0} + \sum_r \zeta_{jr} c_r^h, \quad j = \textit{gasoline, leisure, other goods}$$

where ζ_{j0} and the ζ_{jr}'s are parameters to be estimated. These characteristics include the age, age squared, race, sex (in one-adult estimation only), and education for each adult, the number of children in the household, along with fixed effects for state of residence and the month of the CEX interview.

To correct for the selection bias that may arise because some households do not consume gasoline, we estimate a probit on the choice of whether to consume gasoline, and obtain the inverse Mills ratio (R_g^h) (see West and Williams, 2004a for more detail). Substituting equation (24) into equation (21) and adding R_g^h and error term e_j^h yield the estimation equations:

(25) $$s_j^h = \theta_{j0} + \sum_r \theta_{jr} c_r^h + \sum_k \theta_{jk} \log p_k^h + \theta_j \log\left(y^h / P^h\right) + \theta_j R_g^h + e_j^h.$$

We estimate the demand system defined by (25) separately for one-adult and two-adult households, using working households that consume gasoline, imposing the restrictions in (23a-d) and dropping the equation for other goods. Because some regressors may be endogenous, we use instrumental variables. We use the mean net wage by occupation by state, calculated separately for men and for women, to instrument for the net wage. The real income term $ln(y^h/P^h)$ may also be endogenous, because it is a function of individual-specific shares that are also dependent

[17] For more detail on the TAXSIM model, see Feenberg and Coutts (1993). These tax rate estimates do not include sales taxes or Social Security payroll taxes, and thus will understate the true tax rate. Consequently, this paper's results will tend to understate the importance of second-best effects.

variables. We instrument for this term, using a price index obtained by replacing the individual-specific shares in (22) with the sample mean shares.[18]

Since the equations in (25) are functions of the same explanatory variables, we expect error terms among the equations to be correlated. We therefore estimate the demand system using three-stage least squares (3SLS). This enables us to impose the cross-equation restrictions in equations (20a-d), use instrumental variables to obtain consistent estimates, and use generalized least squares to account for the error correlation structure across equations.[19]

Tables 2 and 3 present the system estimation results along with standard errors based on 1500 replications of a nonparametric bootstrap with observations clustered by household.[20]

Tables 4 and 5 present elasticities for the one-adult and two-adult samples, respectively, along with bias-corrected bootstrap confidence intervals. These elasticities are calculated separately for each household and then aggregated, rather than being calculated for a representative household.[21] Compensated own-price gas and other good demand elasticities are negative, and compensated own-wage labor elasticities are positive. Gasoline own-price elasticity estimates are roughly –0.75 for one-adult households and -0.27 for two-adult households, which fall in the span of estimates reported in gas demand surveys.[22]

For one-adult households, the compensated and uncompensated labor supply elasticities are 0.35 and 0.04, respectively. For two-adult households, compensated own-wage labor supply elasticities are 0.19 for men and 0.34 for women, while uncompensated elasticities are 0.06 and 0.24. These fall into the range reported in the survey by Fuchs *et al.* (1998).

The other important elasticity in equation (18) is the compensated cross-price elasticity of labor with respect to the price of gasoline. All else the same, the higher (less negative) the value of this elasticity, the higher the optimal gas tax, because this implies a smaller reduction in labor supply as a result of the increase in the dirty good tax, and thus a smaller second-best welfare loss. If gasoline is a normal good and leisure is separable in utility, then this elasticity will be negative. This elasticity is indeed negative for one-adult households and for women in two-adult households, though it is significant only for the former group. For men in two-adult households, the estimated elasticity is actually positive (and significant at the 90% level). This

---

[18] Running the demand system with no instruments whatsoever does not noticeably affect the results.

[19] In principle, the full econometric model, including all discrete and continuous choices, might be estimated using maximum likelihood, but this would be difficult to implement. Since censoring occurs in both gasoline and leisure demand, and for either or both the male and female in two-adult households, we would need to evaluate multiple integrals in the likelihood function. Furthermore, such a procedure would probably be too computationally intensive to be practical, given that we need to bootstrap standard errors for our elasticity and optimal tax estimates.

[20] These estimates differ very slightly from those in West and Williams (2004a), even though the estimation procedure is the same, because of improved convergence checking included in the new version of the econometric software package used, which slightly changes the results of the Heckman selection correction.

[21] In many cases, aggregate demand elasticities under the AIDS are equal to the elasticity for a representative household, but that property does not hold when some households are at a corner solution, as is the case here. Thus, it is necessary to aggregate individual household elasticities. See Appendix 1 in West and Williams (2004a) for equations for the household demand elasticities in terms of the estimated parameters.

[22] See Dahl and Sterner (1991) or Espey (1996).

suggests a higher optimal gasoline tax than would be the case if leisure were separable in utility.

One possible explanation for this result is that a higher gas price leads to a reduction in leisure driving that is substantially greater than the reduction in work-related driving (primarily commuting). Parry and Small (2004) note that commuting makes up less than half of all vehicle miles traveled in the US, and it is reasonable to think that the demand for leisure driving would be more elastic than the demand for work-related driving. A more sophisticated argument is that driving is a relatively time-intensive activity (at the margin, once households have incurred the fixed cost of buying a car). Becker's (1965) model of time use suggests that time-intensive goods are complements to leisure (or, more precisely, to non-market time).

IV. Optimal Tax Estimates

This section describes the approach used to estimate the optimal pollution tax rate derived in Section II, then presents and discusses the results of that estimation.

The formula for the optimal pollution tax in expression (18) depends on integrals of various terms over the continuum of households. We estimate the integral of a particular term using the sum of that term over all households in the data set. If the households in the data set are randomly drawn from that continuum then this approach will provide a consistent and unbiased estimate. Intuitively, this sum is the integral over the empirical distribution function, which should be a good estimate of the integral over the true distribution.

The data set includes the necessary price, quantity, and tax rate variables needed for the formula in (18), and the demand system estimation from the previous section provides estimates for the derivatives of gasoline demand and labor supply. We take the value for marginal external damage from Parry and Small (2004), who estimate marginal damages at 83 cents per gallon in year 2000 dollars, a figure that incorporates pollution, congestion and accident externalities. To make this number consistent with the rest of the data, we use the CPI to deflate it, yielding an estimate of 77 cents in 1997 dollars.

The only remaining terms needed are $\tilde{D}(\bar{Y})$ and $\tilde{D}'(\bar{Y})$: the average gasoline consumption as a function of income, and the first derivative of that function. The derivation in Section II assumed a single tax schedule. Here, we extend the model slightly to allow two tax schedules: one for one-adult households and one for two-adult households.[23] Thus, the tax shift used to calculate the optimal dirty-good tax will be distribution-neutral both across different income groups and between one-adult and two-adult households. This changes the formula in (18) only in that there are now two $\tilde{D}(\bar{Y})$ functions, corresponding to the two tax schedules.

If all households had identical preferences, then $\tilde{D}(\bar{Y}^h)$ would equal D^h and $\tilde{D}'(\bar{Y})$ could be calculated from the expenditure elasticity for gasoline. But preferences are allowed to differ, though only in a limited way; the levels of demand for each good (the α_j^h parameters in (21)) can differ across households, but the slopes with respect to prices and income (the γ_{jk} and β_j

[23] It would be more realistic to have one tax schedule for single individuals and one for married couples. This would be substantially more complicated, however, because of the difficulty in allocating gasoline consumption between two unmarried individuals in a household in estimating $\tilde{D}$ and $\tilde{D}'$. A one-adult household consisting of a married person living apart from his or her spouse is even more difficult to handle, because the data set doesn't include information on the spouse.

parameters) cannot, and even the α_j^h's differ only because of the error term and the vector of demographic characteristics. Still, this is enough heterogeneity to allow D^h to vary for households with the same income. And $\tilde{D}'(\bar{Y})$ will depend both on the expenditure elasticity for gasoline and on how the average value of α_g^h varies throughout the income distribution.

Therefore, $\tilde{D}(\bar{Y})$ is estimated by running a variable-bandwidth kernel regression of D^h on the log of income.[24] The estimate of $\tilde{D}'(\bar{Y})$ is the estimated derivative from that kernel regression multiplied by $\bar{Y}$ to yield a derivative with respect to $\bar{Y}$ instead of a derivative with respect to $\ln(\bar{Y})$. This estimation is run separately for the one-adult and two-adult samples.

Substituting these estimates into (18), along with the tax rates, prices and quantities from the data and the estimated derivatives of labor supply and dirty-good demand yield estimates of the optimal gasoline tax. Table 6 presents these estimates along with bootstrap confidence intervals. It shows the estimated optimal gas tax for the one-adult sample, the two-adult sample, and for the two samples together. For each of these three samples, it presents four different estimated tax rates, which differ in the assumptions they make.

The first optimal tax rate estimate assumes that utility is separable and that preferences are constant across the income distribution, implying that the second term in (18) equals zero and thus the optimal tax simply equals the first term. This yields an optimal gas tax of \$0.77 for the one-adult sample, \$0.75 for the two-adult sample, and \$0.75 for the full sample, or just slightly below marginal damage.

Allowing heterogeneity of preferences across the income distribution but retaining the assumption that leisure is separable in utility yields somewhat higher estimates for the optimal gasoline tax rate: \$0.81 for the one-adult sample, \$0.80 for the two-adult sample, and \$0.80 for the full sample. For the one-adult and full samples, the difference between these rates and the previous estimate (without heterogeneity) is significant at the 95% level. For the two-adult sample, it is significant at the 90% level.

This result suggests preferences differ across the income distribution in such a way that even if lower-income households were given the same income as higher-income households, they still would not buy as much gasoline. As a result, the gas tax is slightly less regressive than its expenditure elasticity would suggest, leading to a slightly higher optimal tax.[25]

Relaxing the assumption that leisure is separable in utility yields another set of optimal tax rate estimates: \$0.77 for the one-adult sample, \$1.07 for the two-adult sample, and \$0.91 for the full sample. Thus, allowing nonseparability lowers the optimal tax for the one-adult sample,

---

[24] This regression used a Gaussian kernel, equivalent to using a log-normal kernel over income, which seems appropriate given that income distributions are roughly log-normal. The Gaussian kernel also has a smooth first derivative, which is important for estimating $\tilde{D}'$. Using a variable-bandwidth kernel provides adequate smoothing in the thin tails of the income distribution without oversmoothing the middle of the distribution.

[25] Note that this probably underestimates the effect of heterogeneity in preferences, because the demand system used in this paper only allows very limited heterogeneity; the only differences in the utility function across households come from the error term and the effect of the demographic characteristics of the household. It would be quite interesting to allow more of the utility parameters to vary across households. Unfortunately, estimating such a system would probably be impossible for the data set used here, since it is essentially a cross-section—and cross-section data is inherently incapable of separating income effects from the effects of preferences that vary over the income distribution.

implying that gasoline is a stronger substitute for leisure than would be the case if the utility function were separable. But this estimate is not significantly different from the estimates for either of the two previous cases. In contrast, allowing nonseparability substantially increases the estimated optimal tax for the two-adult sample and the full sample. The differences between these estimates and the corresponding estimates allowing heterogeneity but not nonseparability are significant at the 90% level. The differences from the estimates allowing neither heterogeneity nor nonseparability are significant at the 95% level.

These estimates arise because gasoline is more complementary to leisure than would be the case if the utility function were separable–a result driven primarily by the effect on men in two-adult households. Thus, the combination of a gas tax increase and a compensating income tax cut yields an increase in labor supply, creating a second-best welfare gain. Together with the effect of heterogeneity, this results in an optimal tax rate nearly 20% above marginal damage for the full sample.

Finally, for comparison purposes, we provide estimates using the formula from West and Williams (2004a), which ignores equity in setting the optimal gas tax, focusing entirely on efficiency. This formula yields estimates of \$0.81 for the one-adult sample, \$1.29 for the two-adult sample, and \$1.03for the full sample. Comparing these results to the previous set of estimates shows that taking distributional considerations into account lowers the optimal tax rate. This difference is statistically significant at the 95% level for all three samples.

It is not at all surprising that taking distributional considerations into account leads to a lower optimal tax rate, since it is well-known that the gas tax is regressive. This regressivity can be offset by increasing the progressivity of the income tax system, but that comes at an efficiency cost, thus lowering the optimal tax rate. This effect is substantial, particularly for the two-adult sample and full sample.

V. Conclusions

This paper has calculated the optimal gasoline tax in a model with heterogeneous consumers, a nonseparable utility function, and a pre-existing nonlinear income tax system, taking into account both efficiency and distributional considerations. The results suggest that the optimal tax is roughly \$0.91 per gallon, which is substantially above marginal external damage. This difference arises primarily because gasoline is more complementary to leisure than it would be if the utility function were separable. Consequently, a gax tax increase and an offsetting cut in the income tax yield an increase in labor supply, thus ameliorating the tax distortion in the labor market. In addition, preferences differ across the income distribution in such a way as to slightly increase the optimal tax rate.

This result suggests that the gasoline tax in the United States should be substantially higher than its current level, even when one takes into account the regressive nature of this tax. Numerous prior studies have suggested that gas taxes in the US are too low, but, to our knowledge, none of these studies have incorporated distributional concerns, which are among the most common arguments against higher taxes on gasoline.

The result also suggests that one needs to be careful in applying results on optimal externality taxes from representative-agent models. Most pollution taxes are at least somewhat regressive, and representative-agent models will tend to yield higher optimal tax rates for regressive taxes than will models that incorporate distributional objectives. More applied work should consider the effects of distributional objectives on optimal tax rates, using a framework along the lines of that used in this paper. This framework could also be used to examine optimal taxes on nonpolluting goods.

References

Cremer, Helmuth, Firouz Gahvari, and Norbert Ladoux, 1998, “Externalities and Optimal Taxation,” *Journal of Public Economics* 70:343-364

Cremer, Helmuth, Firouz Gahvari, and Norbert Ladoux, 2003. “Environmental Taxes with Heterogeneous Consumers: An Application to Energy Consumption in France.” *Journal of Public Economics* 87:2791-2815.

Dahl, C., Sterner, T, 1991. Analyzing Gasoline Demand Elasticities: A Survey. *Energy Economics* 13 (3), 203-210.

Deaton, Angus and John Muellbauer, 1980, “An Almost Ideal Demand System.” *American Economic Review* 70: 312-326.

Espey, M., 1996. Explaining the Variation in Elasticity Estimates of Gasoline Demand in the United States: A Meta-Analysis. *The Energy Journal* 17 (3), 49-60.

Feenberg, Daniel and Elisabeth Coutts. “An Introduction to the TAXSIM Model” *Journal of Policy Analysis and Management* (1993).

Fuchs, Victor R., Alan B. Krueger and James M. Poterba, 1998. "Economists' Views about Parameters, Values and Policies: Survey Results in Labor and Public Economics." Journal of Economic Literature 36(3):1387-1425.

Goulder, Lawrence, 2002. “Introduction” in L. Goulder, ed, E*nvironmental Policymaking in Economies with Prior Tax Distortions*, Edward Elgar.

Heckman, James, 1979, “Sample Selection Bias as Specification Error,” *Econometrica* 47, 153-161.

Heien, D. and C. Wessels, 1990, “Demand System Estimation with Micro Data: A Censored Regression Approach,” *Journal of Business and Economic Statistics* 8 (3), 365-1771.

Kaplow, Louis, 1996, “The Optimal Supply of Public Goods and the Distortionary Cost of Taxation,” *National Tax Journal* 49:513-533

Kaplow, Louis, 2004a. “On the (Ir)relevance of Distribution and Labor Supply Distortion to Government Policy,” NBER working paper no. 10490.

Kaplow, Louis, 2004b. “On the Undesirability of Commodity Taxation Even When Income Taxation is Not Optimal.” NBER working paper no. 10407.

Kayser, H. 2000. Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information. Energy Economics 22 (3), 331-348.

Mayeres, I. and Stef Proost, 1997, "Optimal Tax and Public Investment Rules for Congestion Type of Externalities," *Scandinavian Journal of Economics*, 99:261-279

Mayeres, I. and Stef Proost, 2001, "Marginal Tax Reform, Externalities, and Income Distribution," *Journal of Public Economics* 79:343-363

Muellbauer, John, 1975, "Aggregation, Income Distribution and Consumer Demand." *Review of Economic Studies* 62: 525-543.

Muellbauer, John, 1976, "Community Preferences and the Representative Consumer." *Econometrica* 44: 979-999.

Ng, Yew-Kwang, 1984. "Quasi-Pareto Social Improvements." *American Economic Review* 74:1033-1050.

Pigou, A.C., 1938. *The Economics of Welfare* (4th ed.). London: Weidenfeld and Nicolson.

Pirttilä, J. and M. Tuomala, 1997, "Income Tax, Commodity Tax and Environmental Policy," *International Tax and Public Finance*, 4:379-393

Poterba, James, 1991. "Is the Gasoline Tax Regressive?" In Bradford, D. (Ed.), *Tax Policy and the Economy 5*. MIT Press, Boston, pp. 145-164.

Saez, Emmanuel, 2001. "Using Elasticities to Derive Optimal Tax Rates." *Review of Economic Studies* 65:208-229.

Sevigny, M, 1998. *Taxing Automobile Emissions for Pollution Control*. Edward Elgar Publishing Ltd., Cheltenham, UK and Northhampton, MA.

Sipes, K.N., Mendelsohn, R., "The Effectiveness of Gasoline Taxation to Manage Air Pollution" *Ecological Economics* 36 (2), 299-309.

Walls, M.A., Krupnick, A.J., Hood, H.C., 1994. "Estimating the Demand for Vehicle-Miles Traveled Using Household Survey Data: Results from the 1990 Nationwide Transportation Survey." Discussion Paper 93-25 Rev. Resources for the Future, Washington, DC.

West, Sarah and Roberton C. Williams III, 2004a. "Empirical Estimates for Environmental Policy Making in a Second-Best Setting." NBER working paper no. 10330.

West, Sarah and Roberton C. Williams III, 2004b. “Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes.” *Journal of Environmental Economics and Management* 47:535-558.

Table 1: Summary Statistics for Working Households with Non-zero Gas Consumption*

	One-adult Households		Two-adult Households	
Variable	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Gasoline per Week (gallons)	13.78	10.97	24.67	16.07
One-adult Hours per Week	41.25	10.92	-	-
Two-adult Male Hours per Week	-	-	44.76	10.34
Two-adult Female Hours per Week	-	-	37.54	11.09
Gasoline Share of Expenditures	.02	.01	.02	.01
One-adult Leisure Share of Expenditures	.49	.11	-	-
Two-adult Male Leisure Share of Expenditures	-	-	.29	.09
Two-adult Female Leisure Share of Expenditures	-	-	.26	.07
Other Good Share of Expenditures	.50	.15	.44	.12
Gas Price ($)	1.19	.12	1.19	.11
Other Good Price (index)	1.04	.10	1.04	.11
One-adult Heckman-Corrected Net Wage ($)	8.31	2.36	-	-
Two-adult Male Heckman-Corrected Net Wage ($)	-	-	11.02	3.26
Two-adult Female Heckman-Corrected Net Wage ($)	-	-	8.60	2.20
ln(y/P)	5.72	.50	6.23	.45
One-Adult Age (years)	37.2	11.4	-	-
Two-Adult Male Age (years)	-	-	38.5	10.0
Two-Adult Female Age (years)	-	-	37.0	9.5
One-Adult Education: < High School Diploma (%)	6.8	-	-	-
One-Adult Education: High School Diploma (%)	23.3	-	-	-
One-Adult Education: > High School Diploma (%)	69.9	-	-	-
Two-Adult Male Education: < High School Diploma (%)	-	-	8.5	-
Two-Adult Male Education: High School Diploma (%)	-	-	27.9	-
Two-Adult Male Education: > High School Diploma (%)	-	-	63.6	-
Two-Adult Female Education: < High School Diploma (%)	-	-	6.8	
Two-Adult Female Education: High School Diploma (%)	-	-	26.9	-
Two-Adult Female Education: > High School Diploma (%)	-	-	66.4	-
Race of Household Head				
White (%)	82.6	-	87.5	-
Black (%)	13.7	-	8.8	-
Asian (%)	.7	-	.8	-
Other race (%)	3.0	-	2.9	-
Number of Children	.41	.87	1.16	1.18
Region				
Northeast (%)	13.3	-	13.3	-
Midwest (%)	24.5	-	25.8	-
South (%)	34.1	-	35.5	-
West (%)	28.1	-	25.4	-
Observations	6553	-	7162	-

* Of the one-adult households 46% are headed by males while 54% are headed by females.

Table 2: One-adult Household Demand System Estimation Results*

	Gas Share	Leisure Share
ln(gas price)	0.0038	-0.0047
	(0.0026)	(0.0018)
ln(other good price)	0.0009	-0.1071
	(0.0030)	(0.0158)
ln(net wage)	-0.0047	0.1119
	(0.0018)	(0.0160)
ln(y/P)	-0.0131	-0.1829
	(0.0008)	(0.0139)
Inverse Mills Ratio (gasoline)	-0.0150	0.4710
	(0.0018)	(0.0365)
Age	-0.0002	0.0014
	(0.0002)	(0.0026)
Age Squared	0.000002	-0.000014
	(0.000003)	(0.000031)
Black	0.0018	-0.0824
	(0.0007)	(0.0138)
Asian	-0.0010	0.0306
	(0.0028)	(0.0396)
Other Race	0.0003	-0.0483
	(0.0014)	(0.0235)
High School Degree	-0.0059	0.1147
	(0.0014)	(0.0193)
More than High School Degree	-0.0094	0.1619
	(0.0016)	(0.0204)
Female	-0.0041	0.0099
	(0.0006)	(0.0051)
Number of Children	0.0014	-0.0158
	(0.0003)	(0.0041)
Constant	0.1336	1.2255
	(0.0074)	(0.1168)
Number of Observations	6553	6553

* These are 3SLS regressions with ln(mean net wage by occupation, by state) instruments for ln(net wage) and ln(y/P) calculated using the price index based on mean expenditure shares as instruments for ln(y/P) calculated using individual-specific shares. All regressions include state and month dummy variables. Bootstrapped standard errors are in parentheses.

Table 3: Two-adult Household Demand System Estimation Results*

	Gas Share	Male Leisure	Female Leisure
ln(gas price)	0.0102	-0.0061	-0.0031
	(0.0018)	(0.0010)	(0.0009)
ln(other good price)	-0.0011	-0.0604	-0.0491
	(0.0020)	(0.0094)	(0.0075)
ln(male net wage)	-0.0061	0.1383	-0.0717
	(0.0010)	(0.0086)	(0.0052)
ln(female net wage)	-0.0031	-0.0717	0.1239
	(0.0009)	(0.0052)	(0.0069)
ln(y/P)	-0.0090	-0.1687	-0.1694
	(0.0006)	(0.0067)	(0.0050)
Inverse Mills Ratio (gasoline)	-0.0168	0.1820	0.1653
	(0.0024)	(0.0269)	(0.0212)
Male Age	0.0003	-0.0004	0.0006
	(0.0002)	(0.0016)	(0.0011)
Male Age Squared	-0.000003	0.000007	-0.000004
	(0.000002)	(0.000020)	(0.000014)
Black Male	-0.0006	-0.0119	-0.0091
	(0.0015)	(0.0147)	(0.0127)
Asian Male	-0.0011	0.0189	0.0012
	(0.0018)	(0.0149)	(0.0146)
Other Race Male	0.0002	-0.0243	0.0087
	(0.0014)	(0.0110)	(0.0100)
Male High School Degree	-0.0020	0.0132	0.0035
	(0.0010)	(0.0064)	(0.0048)
Male More than High School Degree	-0.0022	0.0192	0.0067
	(0.0011)	(0.0076)	(0.0052)
Female Age	0.0005	0.0007	-0.0031
	(0.0002)	(0.0012)	(0.0013)
Female Age Squared	-0.000005	-0.000006	0.000042
	(0.000002)	(0.000016)	(0.000016)
Black Female	0.0002	-0.0090	-0.0096
	(0.0016)	(0.0149)	(0.0132)
Asian Female	0.0016	0.0037	-0.0218
	(0.0021)	(0.0237)	(0.0110)
Other Race Female	-0.0019	0.0235	-0.0124
	(0.0013)	(0.0103)	(0.0099)
Female High School Degree	0.0004	-0.0044	0.0103
	(0.0009)	(0.0062)	(0.0060)
Female more than High School Degree	0.0004	-0.0032	0.0205
	(0.0010)	(0.0067)	(0.0067)
Number of Children	0.0004	-0.0019	0.0075
	(0.0002)	(0.0013)	(0.0010)
Constant	0.0904	1.3480	1.4282
	(0.0054)	(0.0565)	(0.0444)
Observations	7162	7162	7162

* These are 3SLS regressions with ln(mean net wage by occupation, by state) instruments for ln(net wage) and ln(y/P) calculated using the price index based on mean expenditure shares as instruments for ln(y/P) calculated using individual-specific shares. All regressions include state and month dummy variables. Bootstrapped standard errors are in parentheses.

Table 4: One-Adult Elasticities

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.750	0.180	0.586
	(-1.082 -0.457)	(0.008 0.353)	(0.262 0.936)
Labor	-0.009	0.353	-0.296
	(-0.017 -0.001)	(0.255 0.452)	(-0.385 -0.213)
Other Good	0.0163	0.203	-0.209
	(0.008 0.028)	(0.129 0.235)	(-0.246 -0.140)

Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.771	0.305	0.455
	(-1.087 -0.479)	(0.130 0.471)	(0.092 1.127)
Labor	0.003	0.040	0.024
	(-0.005 0.012)	(-0.079 0.145)	(-0.071 0.134)
Other Good	-0.005	0.621	-1.009
	(-0.014 0.005)	(0.550 0.676)	(-1.072 -0.944)

Bias-corrected 95% confidence intervals are in parentheses, based on 6000 replications of a nonparametric clustered bootstrap.

Table 5: Two-Adult Elasticities

Compensated Price Elasticities	Gas Price	Male Wage	Female Wage	Other Good Price
Gasoline	-0.269	-0.123	0.042	0.354
	(-0.528 -0.004)	(-0.254 0.007)	(-0.055 0.141)	(0.069 0.634)
Male Labor	0.007	0.187	0.012	-0.181
	(-0.001 0.015)	(0.095 0.272)	(-0.018 0.040)	(-0.257 -0.101)
Female Labor	-0.005	0.028	0.337	-0.321
	(-0.017 0.006)	(-0.030 0.082)	(0.249 0.428)	(-0.417 -0.234)
Other Good	0.012	0.102	0.095	-0.201
	(0.002 0.021)	(0.058 0.142)	(0.069 0.123)	(-0.259 -0.141)

Uncompensated Price Elasticities	Gas Price	Male Wage	Female Wage	Other Good Price
Gasoline	-0.283	0.011	0.110	0.178
	(-0.539 -0.018)	(-0.120 0.137)	(0.013 0.209)	(-0.346 0.618)
Male Labor	0.013	0.062	-0.049	-0.045
	(0.005 0.021)	(-0.033 0.147)	(-0.080 -0.020)	(-0.125 0.049)
Female Labor	0.002	-0.113	0.242	-0.165
	(-0.009 0.014)	(-0.174 -0.057)	(0.155 0.331)	(-0.254 -0.071)
Other Good	-0.016	0.548	0.328	-1.090
	(-0.025 -0.006)	(0.492 0.589)	(0.290 0.360)	(-1.152 -1.003)

Bias-corrected 95% confidence intervals are in parentheses, based on 6000 replications of a nonparametric clustered bootstrap.

Table 6: Estimated Optimal Tax Rates

(One-Adult Households Only)

	MED	Optimal Tax Rate
Leisure separable in utility, identical preferences	$0.77	$0.77 ($0.76 $0.79)
Leisure separable in utility, heterogeneous preferences	$0.77	$0.81 ($0.79 $0.84)
Leisure not separable in utility, heterogeneous preferences	$0.77	$0.77 ($0.67 $0.88)
Ignoring equity considerations (from West & Williams, 2004a)	$0.77	$0.81 ($0.72 $0.93)

(Two-Adult Households Only)

	MED	Optimal Tax Rate
Leisure separable in utility, identical preferences	$0.77	$0.75 ($0.73 $0.77)
Leisure separable in utility, heterogeneous preferences	$0.77	$0.80 ($0.73 $2.19)
Leisure not separable in utility, heterogeneous preferences	$0.77	$1.07 ($0.78 $3.32)
Ignoring equity considerations (from West & Williams, 2004a)	$0.77	$1.29 ($0.89 $4.39)

(All Households)

	MED	Optimal Tax Rate
Leisure separable in utility, identical preferences	$0.77	$0.75 ($0.74 $0.77)
Leisure separable in utility, heterogeneous preferences	$0.77	$0.80 ($0.77 $0.94)
Leisure not separable in utility, heterogeneous preferences	$0.77	$0.91 ($0.78 $1.17)
Ignoring equity considerations (from West & Williams, 2004a)	$0.77	$1.03 ($0.87 $1.41)

All monetary values are in 1997 dollars. Bias-corrected 95% confidence intervals are in parentheses, based on 6000 replications of a nonparametric clustered bootstrap. Marginal external damage (MED) includes congestion and accident damages as well as environmental damages. MED estimates are taken from Parry and Small (2004) and deflated from 2000 to 1997 dollars.