

## **Empirical Estimates for Environmental Policy Making in a Second-Best Setting**

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## **Empirical Estimates for Environmental Policy Making in a Second-Best Setting**

### **Abstract**

This study estimates parameters necessary to calculate the optimal second-best gasoline tax, most notably the cross-price elasticity between gasoline and leisure. Despite prior work showing that the cost of environmental regulation in the presence of a pre-existing labor tax depends strongly on this elasticity, no prior study has estimated the cross-price elasticity between a polluting good and leisure. Using household data, we find that gasoline is a relative complement to leisure, implying that the optimal second-best gasoline tax exceeds marginal damages and is thus substantially higher than indicated by prior studies. This result suggests that the cross-price elasticity with leisure should be estimated for other major polluting goods, and such estimates should be incorporated into future calculations of the second-best optimal taxes on polluting goods.

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## I. Introduction

The extensive literature on environmental regulation with pre-existing distortions has shown that the optimal environmental tax in such a setting can be substantially different than in a partial-equilibrium model (for a recent survey, see Goulder, 2001). Two general-equilibrium effects appear in the presence of a distortionary labor tax. The *revenue-recycling effect* is the welfare gain from using environmental tax revenues to cut the rates of pre-existing distortionary taxes. But the revenue-recycling effect is accompanied by the *tax-interaction effect*; environmental taxes increase the price of the polluting good, which raises the overall price level, lowering the real wage, thus discouraging labor supply and creating a second-best welfare loss.

This tax-interaction effect is difficult to calculate, because its magnitude and even sign depend on the cross-price elasticity between the polluting good and leisure; the more substitutable is the polluting good for leisure, the larger the welfare loss. If the polluting good and leisure are complements, the tax-interaction effect can generate a welfare gain. To obtain a practical expression for this effect, prior work has typically assumed either that the polluting good is an average substitute for leisure, or, that the utility function is homothetic and weakly separable between leisure and consumption (implying that all goods are average substitutes for leisure).

Empirical studies that estimate the joint demand for goods and leisure decisively reject separability, but do not offer estimates of the cross-price elasticities between leisure and polluting goods.<sup>1</sup> Indeed, the literature on second-best environmental regulation consists entirely of analytical and numerical models, with no empirical work. Several recent papers (Goulder, 2000 and 2001, and Fullerton and Gravelle, 1999, for example) identify empirical estimation as the next necessary step in addressing unanswered questions in this literature.

This paper takes a step toward answering these questions, by estimating the cross-price elasticity between gasoline and leisure and using that estimate to calculate the optimal second-best gasoline tax. We use the 1996 through 1998 Consumer Expenditure Surveys, which provide detailed data on household expenditures including gasoline expenditures, on vehicle holdings,

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<sup>1</sup> Separability has been tested and rejected in many studies (Abbott and Ashenfelter (1976, 1979), Alderman and Sahn (1993), Asano et al. (1997), Barnett (1979), Blundell and Walker (1982), Browning and Meghir (1991), Dowd (1992), Kaiser (1993), and Molina (1999)). Diewert and Lawrence (1996) use macro-level data from New Zealand to estimate the cross-price elasticity between motor vehicles and leisure. They do not consider gasoline or miles driven.

and on each individual's wages and working hours. Due to the difficulty in modeling the complicated, interdependent labor supply decisions that arise in multiple-adult households, we consider only households with one adult present. 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. We resolve this issue by using 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 find that the optimal second-best gasoline tax is roughly 22% higher than marginal external damage. In contrast, the prior literature on second-best environmental taxes often suggests that the optimal tax will generally be less than marginal external damage. Our result differ for two reasons. First, we find that the uncompensated labor supply elasticity is slightly negative for our single individuals, which causes the optimal tax to be slightly greater than marginal damages. The second and more important reason is that we find that gasoline is more complementary to leisure than is the average good, which leads to a substantially higher optimal tax rate.

The next section of this paper develops a simple theoretical model and derives an expression for the optimal second-best environmental tax. Subsequent sections describe the empirical model, data, estimation results, and the implied optimal environmental tax. The final section presents conclusions and suggests directions for future research.

## **II. A Theoretical Model**

This section presents a simple theoretical model and uses it to derive an expression for the optimal second-best environmental tax. This model is similar to those used in the prior

literature, but, unlike most earlier work, does not assume that leisure is separable, that the utility function is homothetic, or that the polluting good is an average substitute for leisure.<sup>2</sup>

The model assumes a representative agent, who divides his or her time endowment ( $T$ ) between leisure ( $l$ ) and labor ( $L$ ), which is used to produce a dirty consumption good ( $D$ ), a clean good ( $C$ ), and a government-provided public good ( $G$ ).<sup>3</sup> The agent's utility function is

$$(1) \quad U(l, C, D, G) - \phi(D)$$

where  $U$  is continuous and quasi-concave.<sup>4</sup>

The government levies taxes on labor income (at the rate  $\tau_L$ ) and consumption of the dirty good (at the rate  $\tau_D$ ). The consumer budget constraint is

$$(2) \quad p_C C + p_D D = wL + I$$

where  $p_D$  is the consumer price for the dirty good, and  $w$  is the net wage. The consumer price of the clean good is normalized to equal one. Non-labor income,  $I$ , is assumed to equal zero but is included in the model to allow rigorous expressions for income effects. The consumer price of the dirty good is defined by

$$(3) \quad p_D = \bar{p}_D + \tau_D$$

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<sup>2</sup> Recent papers that use a very similar model, but assume homotheticity and separability in deriving optimal tax expressions include Williams (2001a), Goulder *et al.* (1999), and Parry, Williams, and Goulder (1999). Parry and Small (2001) and Ballard *et al.* (2000) relax the assumption of homotheticity, but maintain separability. Kim (forthcoming) provides a theoretical model that derives an expression for the optimal pollution tax without imposing separability or homotheticity, but does not include any empirical estimates using that expression.

<sup>3</sup> This specification could also represent unproductive government spending (in which case  $\partial U / \partial G = 0$ ).

<sup>4</sup> Note that we still assume that the damage from the externality is additively separable in utility. If damages were to enter in some other form, that could also generate a second-best welfare effect. See Williams (2001b) or Espinosa and Smith (2001) for further discussion. The present paper focuses on the importance of the polluting good being separable in utility, and thus ignores the question of whether damages are separable or not.

where  $\bar{p}_d$  is the producer price for the dirty good. The price normalization (that the consumer price of the clean good is one) and tax normalization (that there is no tax levied on the clean good) together imply that the producer price of the clean good is one. The net wage is defined by

$$(4) \quad w = \bar{w} - \tau_L$$

where  $\bar{w}$  is the gross wage.

Tax revenue is used to finance a fixed level of the public good.<sup>5</sup> The labor tax rate is assumed to vary to hold the level of  $G$  fixed for changes in the dirty-good tax. Thus, the government budget constraint is

$$(5) \quad \tau_d D + \tau_L L = \bar{p}_G G$$

where  $\bar{p}_G$  is the producer price of the public good. Each of the three goods is produced from labor under perfect competition with constant returns to scale. This implies that  $\bar{p}_d$ ,  $\bar{p}_G$ , and  $\bar{w}$  are exogenously fixed. The household time constraint follows

$$(6) \quad T = l + L = l + \frac{1}{\bar{w}} C + \frac{\bar{p}_d}{\bar{w}} D + \frac{\bar{p}_G}{\bar{w}} G$$

Households maximize utility (1) subject to their time constraint (6) and budget constraint (2), taking prices, tax rates, the level of the public good, and the level of pollution as given. This yields the first-order conditions

$$(7) \quad U_c = \lambda; U_d = p_d \lambda; U_l = w \lambda$$

where  $\lambda$  is the marginal utility of after-tax income. Together with the constraints given previously, these implicitly define the (uncompensated) demand functions

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<sup>5</sup> The model would yield the same result under the alternative assumption that government revenue is spent on a lump-sum transfer to households, as long as the purchasing power of that transfer is held constant.

$$(8) \quad C(p_D, w, I); D(p_D, w, I); l(p_D, w, I)$$

Taking a total derivative of utility (1) with respect to  $\tau_D$ , substituting in the first-order conditions (7), subtracting  $w$  times the total derivative of the household time constraint (6) with respect to  $\tau_D$ , and rearranging terms yield

$$(9) \quad \frac{1}{\lambda} \frac{dU}{d\tau_D} = (\tau_D - \tau_P) \frac{dD}{d\tau_D} - \tau_L \frac{dl}{d\tau_D}$$

where  $\tau_P$  is the Pigouvian tax, which is equal to the dollar value of the marginal damage from pollution

$$(10) \quad \tau_P = \frac{1}{\lambda} \frac{\partial \phi}{\partial D}$$

We now define two terms that represent the cost of the labor tax. These will be useful in expanding the terms from (9).

First, we define  $\eta$ , which is the marginal cost of public funds (MCPF), and is given by

$$(11) \quad \eta = 1 + \frac{-\tau_L \frac{\partial l}{\partial w}}{L + \tau_L \frac{\partial l}{\partial w}} = \frac{L}{L + \tau_L \frac{\partial l}{\partial w}}$$

This is the marginal cost to households of raising government revenue through a change in the labor tax or clean-good tax; thus, it is the ratio of the loss to households from a marginal increase in either of these taxes to the marginal revenue raised.<sup>6</sup>

The second term in (9) can now be shown to equal

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<sup>6</sup> The definition of the MCPF is “non-environmental” in that it omits the effects of changes in environmental quality and ignores the revenue from the environmental tax.

$$(12) \quad -\tau_L \frac{dl}{d\tau_D} = \eta \frac{\tau_L}{w} D s_C (\varepsilon_{DL} - \varepsilon_{CL}) + (\eta - 1) \tau_D \frac{dD}{d\tau_D}$$

where  $s_C$  is the expenditure share of the clean good, given by

$$(13) \quad s_C = \frac{C}{p_D D + C}$$

and where  $\varepsilon_{DL}$  and  $\varepsilon_{CL}$  are the compensated cross-elasticities between leisure and the dirty and clean goods, respectively. These are given by

$$(14) \quad \varepsilon_{DL} = \frac{\partial D^C}{\partial w} \frac{w}{D}$$

and

$$(15) \quad \varepsilon_{CL} = \frac{\partial C^C}{\partial w} \frac{w}{C}$$

where the superscript “C” denotes the compensated demand function.

Setting (9) equal to zero and substituting in (12) yield an expression for the optimum tax on the dirty good

$$(16) \quad \tau_D^* = \frac{\tau_P}{\eta} - \frac{D}{\frac{dD}{d\tau_D}} \eta \frac{\tau_L}{w} s_C (\varepsilon_{DL} - \varepsilon_{CL})$$

Thus the optimum tax on the dirty good is the sum of two terms. The first term is the traditional Pigouvian tax, adjusted by the marginal cost of public funds, where the MCPF depends on the compensated and uncompensated responses of labor supply to changes in the wage rate. The second term accounts for the relationship between the dirty and clean goods and labor. This term will equal zero if the dirty and clean goods are equal substitutes for leisure. If

the dirty good is more substitutable for leisure than the clean good, then this second term will be positive; conversely, if it is less substitutable for leisure, this term will be negative.

### III. An Empirical Model

To determine the optimal tax on the dirty good in (16), one needs to know the signs and magnitudes of the compensated and uncompensated elasticities of labor, the own price elasticities of the “dirty” and clean goods, and the cross-price elasticities of these goods with respect to leisure. In this section, we specify the Almost Ideal Demand System (AIDS) that we use to obtain these elasticities.

#### A. Demand System Specification

We consider the demand for leisure, gasoline, and all other goods. To estimate this demand system, we use the Almost Ideal Demand System (AIDS), first derived by Deaton and Muellbauer (1980). The advantages of this system are well-known: it gives an arbitrary first-order approximation to any demand system, satisfies the axioms of choice exactly, is simple to estimate, and can be used to test the restrictions of homogeneity and symmetry.

The AIDS provides these advantages because it is derived from a preference structure characterized by the expenditure function proposed in Muellbauer (1975, 1976):

$$(20) \quad \log c(\mathbf{p}, w, u) = (1-u) \log[a(\mathbf{p}, w)] + u \log[b(\mathbf{p}, w)]$$

where  $\mathbf{p}$  is a vector of commodity prices and  $w$  is the wage,  $u$  is utility, and where:

$$(21) \quad \log a(\mathbf{p}, w) = \alpha_0 + \sum_k^{n,l} \alpha_k \log p_k + \frac{1}{2} \sum_k^{n,l} \sum_j^{n,l} \gamma_{kj} \log p_k \log p_j$$

$$(22) \quad \log b(\mathbf{p}, w) = \log a(\mathbf{p}, w) + \beta_0 \prod_k^{n,l} p_k^{\beta_k}$$

Applying Shepard’s Lemma, we obtain the demand equations for goods and leisure, in their budget share forms:

$$(23a) \quad s_i = \alpha_i + \sum_j^{n,l} \gamma_{ij} \log p_j + \beta_i \log\left(\frac{y}{P}\right) \quad (i = \text{gasoline, other goods})$$

$$(23b) \quad s_l = \alpha_l + \sum_j^{n,l} \gamma_{ij} \log p_j + \beta_l \log\left(\frac{y}{P}\right)$$

where  $y$  is total income (total spending on gas, leisure and other goods) and  $P$  is the price index defined by:

$$(24) \quad \log P \equiv \sum_k^{n,l} s_k \log p_k$$

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

$$(25) \quad \sum_{i=1}^n \alpha_i = 1$$

$$(26) \quad \sum_{i=1}^n \gamma_{ij} = 0$$

$$(27) \quad \sum_{i=1}^n \beta_i = 0$$

$$(28) \quad \gamma_{ij} = \gamma_{ji}$$

Provided that these restrictions hold, (23) represents a system of demand functions that add up to total expenditure, are homogeneous of degree zero in prices and total expenditure, and that satisfy Slutsky symmetry. Budget shares sum to one. We impose (25) through (28) and drop the equation for other goods.

#### IV. Data

To estimate the model discussed above, we need data on expenditures, prices, wages, hours worked, and household and vehicle characteristics. This section describes the two main sources of data used in this study: the Consumer Expenditure Survey (CEX) and the American Chamber of Commerce Researchers' Association (ACCRA) cost-of-living index. It also describes the derivation of variables used in the estimation and provides summary statistics.

##### A. Data Description and Variable Derivation

The 1996 through 1998 Consumer Expenditure Surveys (CEX) are the main components of our data. The CEX Family Interview files include the amount spent by each household on

gasoline, total expenditures, information on each household's vehicles, and a wide variety of income measures. For each household member, the Member Files include usual weekly hours, occupation, the gross amount of last pay, the duration of the last pay period, and a variety of member income measures. The CEX is a rotating panel survey. Each quarter, 20 percent of the sample is rotated out and replaced by new consumer units. We use data for each household from the first quarter in which the household appears.

Because households with more than one adult have complicated, interdependent labor supply decisions, we use only households with one adult present. Individuals in this group generally have less flexibility in their labor supply decisions than do members of multiple-adult households, as demonstrated by prior studies that have found married women to have much higher labor supply elasticities than do unmarried women.<sup>7</sup> This suggests that whatever response we find in one-adult households is likely to be substantially stronger in the population as a whole.

For gas prices and the price of other goods, we use the ACCRA cost-of-living index. This index compiles prices of many separate goods as well as overall price levels for approximately 300 cities in the United States. It is most widely used to calculate the difference in the overall cost-of-living between any two cities. It also lists for each quarter the average prices of regular, unleaded, national-brand gasoline. 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. We use the price index as our price of other goods.

Total income ( $y$  in equation (23) above)) equals the amount spent on gasoline, leisure, and all other goods. The CEX contains quarterly gasoline expenditure. Since it also contains hours worked per week, we divide quarterly gasoline expenditure by 13 to get weekly gas expenditure. To derive weekly leisure "expenditure", we assume that the total number of hours available either to work or to consume leisure is equal to 12 hours per day, 7 days a week (for a total of 84 hours per week). We then subtract the number of hours worked per week from 84 to get hours of leisure per week. To obtain the price of leisure (the wage) we first calculate the wage net of tax using state and federal effective tax rates generated from the NBER's TAXSIM

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<sup>7</sup> See Blundell and MaCurdy (1999) for a survey of the empirical literature on labor supply elasticities.

model (see Feenberg and Coutts, 1993). Then, since we do not observe wages for individuals who are not working, we follow Heckman (1979) to correct for this selectivity bias to obtain selectivity-corrected net wages. We multiply weekly leisure hours and net wage rates to obtain leisure expenditures per week.

To calculate weekly spending on other goods, we first convert the CEX's measure of quarterly total expenditures into weekly total expenditures. Then, we subtract weekly gasoline expenditure from total weekly expenditures to obtain spending on all other goods.

### *B. Summary Statistics*

The twelve quarters in the 1996 through 1998 Consumer Expenditure Surveys have 5046 individuals from one-adult households with complete records of the variables needed here. Of those 5046 individuals, 1393 do not work at all. We use all 5046 to correct for selection bias in the wage, and we use the 3653 working individuals in demand system estimation. Table 1 lists summary statistics for the sample of workers.

Households spend about 2 percent of their income on gasoline, 52 percent on leisure, and the remainder on other goods. The average selectivity-corrected wage in the sample is \$9.73 per hour, with a standard deviation of \$3.05 per hour. These are similar to the average wage paid to hourly workers in the 1997 March Current Population Survey (\$10.09 with a standard deviation of \$5.67). The overall wage distribution in our sample also closely follows the wage distribution in the 1997 CPS.

## **V. Estimation**

The main estimation issues relate to the potential endogeneity of the regressors. In particular, the net marginal wage may be endogenous for two reasons. First, the gross wage is determined by dividing earnings by hours of work, and both variables may be measured with some error. Thus hours worked and wages may be correlated. Second, the marginal income tax rate depends on income. We therefore use occupation to instrument for the net wage. We also correct for potential endogeneity in gas prices by using state gas tax rates as instruments.<sup>8</sup>

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<sup>8</sup> Regressions without instruments generate results that are very similar to those presented here.

In addition, if some households have zero expenditure on one or more of the goods, then another selection bias may arise. To address this concern, we use a probit to estimate the dichotomous decision to consume or not to consume. These regressions provide estimates for inverse Mills ratios, which we then include in estimation of the AIDS system.<sup>9</sup>

Last, gasoline expenditures are related to automobile choice. Estimates will be biased unless we control for the endogeneity of vehicle choice in the demand for gasoline(see Goldberg (1998) and Train (1986)). To correct partially for this endogeneity, we include the number of vehicles in the household in the share equations.<sup>10</sup>

We impose the restrictions in (25) through (28), drop the equation for other goods, and estimate the system using three-stage least squares. We include in the system member characteristics that may affect gasoline or leisure shares: the members' age, age squared, race, sex, education, and number of children. We also include state-level characteristics: population density, average drive time, and unemployment rate. Since these state-level data vary across the twelve quarters in our sample, we also include state dummy variables to account for other state-level sources of variation not captured by the included state-level characteristics.

Tables 2 contains estimation results for the gas share equation . The share of gasoline increases with the wage and is higher for less-educated individuals, non-whites, males, or those with more cars, and those living in states with longer average drive times or lower population densities. Table 3 contains results for the leisure share equation. The share of leisure decreases with the wage and the price of gasoline, and it increases with the price of the other good. Leisure share is higher for more-educated individuals, males, individuals with more children, with more cars or in states with longer average drive times.

Table 4 translates coefficient estimates into elasticity estimates. All compensated own-price elasticities are negative. Compensated and uncompensated gasoline own-price elasticities are about -.6, which fall in the range of estimates reported in gas demand survey articles (see

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<sup>9</sup> Alderman and Sahn (1993) and Heien and Wessels (1990) also use this procedure. These discrete-choice estimates are available from the authors by request, as are the estimates used to correct wages for selectivity bias.

<sup>10</sup> A better way to correct for the endogeneity of vehicle choice in the demand for gasoline would be to estimate the discrete choice of vehicle, including the operating cost of the vehicle in the estimation, and then to include the predicted probability of each vehicle being chosen in the gasoline equation. This, however, requires measurements of fuel efficiency that are not available in the CEX (see West, 2001).

Dahl and Sterner (1991) or Espey (1996)). Uncompensated leisure demand elasticities are positive; in this sample the income effect of the wage dominates. This result is probably attributable, in part, to our restricted sample that includes only single-adult households. As noted in the previous section, prior studies have suggested that labor supply is much more elastic for married women, who are excluded from our sample.

Compensated cross-price elasticities indicate that gasoline and are weak complements, while other goods and leisure are substitutes. The compensated cross-price elasticity of gasoline with respect to leisure is  $-.045$ , which is close to zero. The chi-squared from a nonlinear Wald test indicates that this estimate is not statistically different from zero. The coefficients that are used to calculate this elasticity are those on  $\ln(\text{wage})$  in the gasoline share equation, the coefficient on  $\ln(y/P)$  from the gas share equation and the coefficient on  $\ln(y/P)$  in the leisure share equation. The first two of these coefficients are statistically significant.<sup>11</sup>

## **VI. Optimal Tax Calculations**

This section uses the elasticity estimates from the previous section to calculate the optimal second-best gasoline tax rate, and compares that to the rate that one would get from an optimal tax formula that assumes separability and homotheticity, as in most of the prior literature.

Table 4 provides values for nearly all of the variables and parameters in the formula for the optimal tax rate (16) and the formula for the marginal cost of public funds (11).<sup>12</sup> The only additional values needed are the share of the clean good in consumption, the labor tax rate, and

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<sup>11</sup> We cannot reject the hypothesis that the cross-price elasticity between gas and leisure is equal to that between other goods and leisure. While we proceed to use the elasticity point estimates to calculate one second-best tax rate, we recognize that our estimates imply a large range of possible tax rates. We will address this in future drafts.

<sup>12</sup> This assumes that the elasticities at the optimum (the necessary parameters for equations (11) and 16)) are similar to those present in the status quo (which are what we estimated). In addition, by assuming a representative agent, we are ignoring heterogeneity among consumers. This is important for two reasons. First, our empirical work suggests that elasticities will differ slightly across consumers. Using only a single elasticity value may alter our results, though this effect should be small, because we are implicitly using the average elasticity over all consumers. Second, we cannot address distributional concerns, which may significantly affect the optimal tax rate. See the conclusion for further discussion on this latter point.

the marginal external damage from gasoline.<sup>13</sup> We convert the share of the clean good in “virtual spending” from Table 1 into a share of consumption spending only, in order to match the definition used in (16). We could use the average tax rate from our data set (as calculated by the TAXSIM model), but instead simply assume a total tax rate of 40% for consistency with the prior literature on second-best environmental taxation. Finally, we take the value for marginal external damages from gasoline consumption from Parry and Small’s (2001) recent survey, which estimates marginal damages at 95 cents per gallon, a figure that incorporates pollution, congestion and accident externalities.

Substituting the appropriate parameter values into equation (11) yields an estimate of 0.95 for the MCPF. This differs significantly from prior work, which has almost universally assumed or estimated that the MCPF exceeds one. The source of the difference is that our estimate for the uncompensated elasticity of labor supply is negative: that is, an uncompensated increase in the net wage will yield a reduction in labor supply, because the income effect of the increased wage is stronger than the substitution effect. This implies that raising the labor tax rate will encourage labor supply, and thus produce a second-best welfare gain in the labor market. Consequently, the cost to the representative agent of raising a dollar of government revenue is actually less than a dollar, because the gain in the labor market offsets part of the cost.<sup>14</sup> Prior work on second-best environmental taxes has assumed a positive uncompensated labor supply elasticity, implying a MCPF greater than 1.

The now-standard formula from the prior literature, which assumes that the polluting good is an average substitute for leisure (or makes the slightly stronger assumption that utility is homothetic and separable), states that the optimal second-best tax is equal to marginal damages divided by the marginal cost of public funds (MCPF). This would imply a gas tax of \$1 per gallon. This tax slightly exceeds marginal damages (.95), because the MCPF is slightly less than 1. In this case, the negative uncompensated labor supply elasticity implies that the signs of the

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<sup>13</sup> Equation (16) also includes the total derivative of gasoline consumption with respect to the gas tax. This derivative is neither strictly uncompensated (because the labor tax cut, which is included in the total derivative, provides some compensation) nor strictly compensated (because the labor tax cut does not fully compensate for the change). However, as long as the tax rates are relatively small, this total derivative will be very close to the compensated derivative, and thus we simply use the compensated elasticity.

<sup>14</sup> See Ballard and Fullerton (1992) for further discussion of how and why the MCPF can be below one, and of the implications of this for the optimal provision of public goods.

revenue-recycling and tax-interaction effects are reversed from what is suggested in the prior literature. The welfare gain to households from lowering the labor tax is less than the amount of revenue recycled, so the revenue-recycling effect yields a welfare loss. But the decrease in the real wage caused by the increased gas price results in a labor supply increase, implying a welfare gain from the tax-interaction effect. Just as in prior work, the magnitude of the tax-interaction effect slightly exceeds the magnitude of the revenue-recycling effect, and so the net result of the two general-equilibrium effects is to raise the optimal tax.

Relaxing the assumption that gasoline is an average substitute for leisure gives the optimal tax formula from equation (16). When we substitute the appropriate parameter estimates into (16), we get a second-best optimal gasoline tax of \$1.16 per gallon, significantly higher than marginal damages and higher than the optimal tax from the standard second-best formula. The tax exceeds marginal damages both because the MCPF is less than one and because our cross-price elasticity point estimates indicate that gasoline is more complementary to leisure than is the average good. This implies that increasing the tax on gasoline will increase labor supply by more than an equivalent increase in the tax on other goods, and thus that the gain from the tax-interaction effect will be larger than it would be if gasoline were an average substitute for leisure. Thus, the optimal tax rate is higher.<sup>15</sup>

The difference between the optimal second-best tax and marginal external damage—a difference of 21 cents per gallon—is not dramatic, but the use of these point estimates suggests that it is substantial enough to be important in practice. And this difference has the opposite sign from what the prior literature has suggested. That literature has certainly noted the theoretical possibility that the optimal tax may exceed marginal damage, for exactly the reasons found here, but gave no sense of how likely such an outcome might be.

Comparing the impact of including second-best effects with and without assuming separability and homotheticity demonstrates the importance of these assumptions. Given these point estimates, the difference caused by relaxing the assumptions of separability and

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<sup>15</sup> If the uncompensated labor supply elasticity were positive, the finding that gasoline is a relative complement to leisure would still raise the optimal second-best gasoline tax. In that case, the tax-interaction effect would yield a welfare loss if gasoline were an average substitute for leisure. Gasoline being a relative complement to leisure would imply a smaller loss, or perhaps even a gain, and thus a higher optimal tax.

homotheticity (a rise from \$1 to \$1.16 in the optimal tax) is more than three times as large as the difference caused by incorporating second-best effects in the first place (\$0.95 to \$1).

## **VII. Conclusions**

This paper has estimated a complete consumer demand system that does not impose separability or homotheticity, and has put those estimates together with a simple theoretical model of optimal second-best environmental taxation to calculate the optimal tax on gasoline. Contrary to the prior literature, which has suggested that the second-best optimal tax is less than marginal external damage, we found that the optimal tax is substantially above marginal damage. The difference arises primarily because our point estimates suggest that gasoline is more complementary to leisure than is the average good, while the prior literature generally assumes that the polluting good is an average substitute for leisure.

This result has important implications both for policy and for future research. The most obvious policy implication is that the optimal gasoline tax might be substantially above marginal external damage, and, correspondingly, that the efficiency gain from an increase in the gasoline tax might be larger than a first-best analysis would indicate. Of course, the practical relevance of this result is limited by political constraints on gasoline taxes; the existing tax is far below what almost any economic analysis would indicate as the optimum.

This result also suggests that when taking second-best effects into account for setting other environmental taxes, policy makers should recognize that there is a lot more uncertainty about these effects than prior work has suggested; the possibility that such effects will cause the optimal tax to exceed marginal damages has practical relevance, rather than being merely a theoretical possibility.

Our results also suggest several directions for future research. It would be interesting, and potentially important, to apply this empirical work to other polluting goods. This would permit better estimates of the optimal taxes those other goods, and would also provide a better sense of whether polluting goods in general tend to be leisure complements or substitutes.

This study also has a number of limitations that could be addressed by future work. First, we consider only one-earner households, due to the difficulty of estimating labor supply in multiple-earner households. Given that one-earner households generally have less flexibility in

their labor-supply decisions, labor elasticities – both own-price and cross-price – will probably be larger for the population as a whole than for our sample. Extending this work to a broader sample would be useful.

Second, our theoretical model of optimal second-best environmental taxes assumes a representative agent. Consequently, it cannot take into account distributional concerns, which may be important in taxing gasoline, because gasoline taxes are generally considered to be significantly regressive. It would be interesting to see how these optimal tax results would change in a model with multiple agents, where distributional concerns can be explicitly considered.

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**Table 1: Summary Statistics for the Sample of Workers used in Estimation**

<b>Variable</b>	<b>Mean</b>	<b>Standard Deviation</b>
Gasoline per Week (gallons)	12.07	11.82
Hours per Week	40.36	11.90
Gasoline Share of Expenditures	0.02	0.02
Leisure Share of Expenditures	0.52	0.16
Other Good Share of Expenditures	0.47	0.16
Gas Price (\$)	1.19	0.11
Other Good Price (index)	103.99	10.51
Net Wage (\$)	9.73	3.05
ln(y/P)	3.39	0.33
State Gasoline Tax Rate (\$)	0.19	0.05
Education		
Less than High School Diploma (%)	8.0	-
High School Diploma (%)	26.0	-
More than High School Diploma (%)	66.0	-
Race		
White (%)	80.4	-
Black (%)	15.8	-
Asian (%)	.77	-
Other race (%)	3.04	-
Female (%)	56.00	-
Number of Kids	0.42	0.90
Region		
Northeast (%)	15.36	-
Midwest (%)	24.12	-
South (%)	32.36	-
West (%)	28.17	-
Number of Vehicles	1.09	1.02
State Average Drive Time to Work (minutes)	22.10	2.91
State Population Density (persons/mile <sup>2</sup> )	235.05	555.69
State Unemployment Rate (%)	4.95	1.14

**Table 2: Gas Share Equation Estimates**

	<b>Coefficient Estimate</b>	<b>Standard Error</b>	<b>Z-Statistic</b>
ln(gas price)	0.0063631	0.0109406	0.58
ln(wage)	-0.0085145	0.0017497	-4.87
ln(other good price)	0.0021514	0.0108341	0.2
ln(y/P)	-0.0008954	0.0008026	-1.12
Age	0.0001288	0.0001973	0.65
Age Squared	-0.000002	.000002	-1.01
High School Degree	-.00475	0.0010649	-4.46
More than High School Degree	-0.00674	0.0011924	-5.65
Black	0.0014149	0.0007867	1.8
Asian	0.0021161	0.0029161	0.73
Other Race	0.0023643	0.0015465	1.53
Female	-0.0040139	0.0006163	-6.51
Number of Kids	-0.0001542	0.0003262	-0.47
Number of Vehicles	0.0015928	0.0003455	4.61
State Average Drive Time to Work (minutes)	0.0009226	0.0003769	2.45
State Population Density (persons/miles <sup>2</sup> )	-0.0000354	0.0000171	-2.06
State Unemployment Rate	0.0007636	0.0005157	1.48
Inverse Mills Ratio for Gasoline	-0.0148667	0.0011738	-12.67
Constant	0.0166743	0.0485996	0.34
Number of Observations	3653		
Pseudo R-squared	0.1629		
Chi-squared	709.1725		

**Table 3: Leisure Share Equation Estimates**

	<b>Coefficient Estimate</b>	<b>Standard Error</b>	<b>Z-Statistic</b>
ln(gas price)	-0.0085145	0.0017497	-4.87
ln(wage)	-0.1121747	0.0130267	-8.61
ln(other good price)	0.1206893	0.0130648	9.24
ln(y/P)	0.3117055	0.0060294	51.7
Age	0.0016636	0.001465	1.14
Age Squared	-.00000874	0.0000172	-0.51
High School Degree	0.0092975	0.0079945	1.16
More than High School Degree	0.0216066	0.0089506	2.41
Black	-0.0091309	0.0059117	-1.54
Asian	0.0424931	0.0219177	1.94
Other Race	-0.0557421	0.0115992	-4.81
Female	-0.0100742	0.0045909	-2.19
Number of Kids	-0.0169824	0.0024442	-6.95
Number of Vehicles	-0.015313	0.0025926	-5.91
State Average Drive Time to Work (minutes)	-0.0087153	0.0028236	-3.09
State Population Density (persons/miles <sup>2</sup> )	0.0000378	0.0001265	0.3
State Unemployment Rate	0.0006993	0.0035917	0.19
Inverse Mills Ratio for Gasoline	0.1173642	0.0088069	13.33
Constant	-0.7339233	0.0801248	-9.16
Number of Observations	3653		
Pseudo R-squared	0.5204		
Chi-squared	3990.279		

**Table 4: Elasticities**

<b>Compensated Price Elasticities</b>			
	Gas Price	Wage	Other Good Price
Gasoline	-0.606 (0.88)	-0.045 (0.16)	0.651 (1.03)
Leisure	-0.001 (0.16)	-0.063* (3.39)	0.064* (3.55)
Other Good	0.024 (1.03)	0.071* (3.55)	-0.094* (4.58)
<b>Uncompensated Price Elasticities</b>			
	Gas Price	Wage	Other Good Price
Gasoline	-0.622 (0.92)	0.465 (0.16)	0.208 (1.03)
Leisure	-0.029 (0.16)	0.129* (369.53)	-0.687* (3.55)
Other Good	0.018 (1.03)	0.877* (3.55)	-0.251* (27.78)

Chi-squared statistics for nonlinear-Wald tests are in parentheses.

\* Statistically significantly different than zero at the 5% level.